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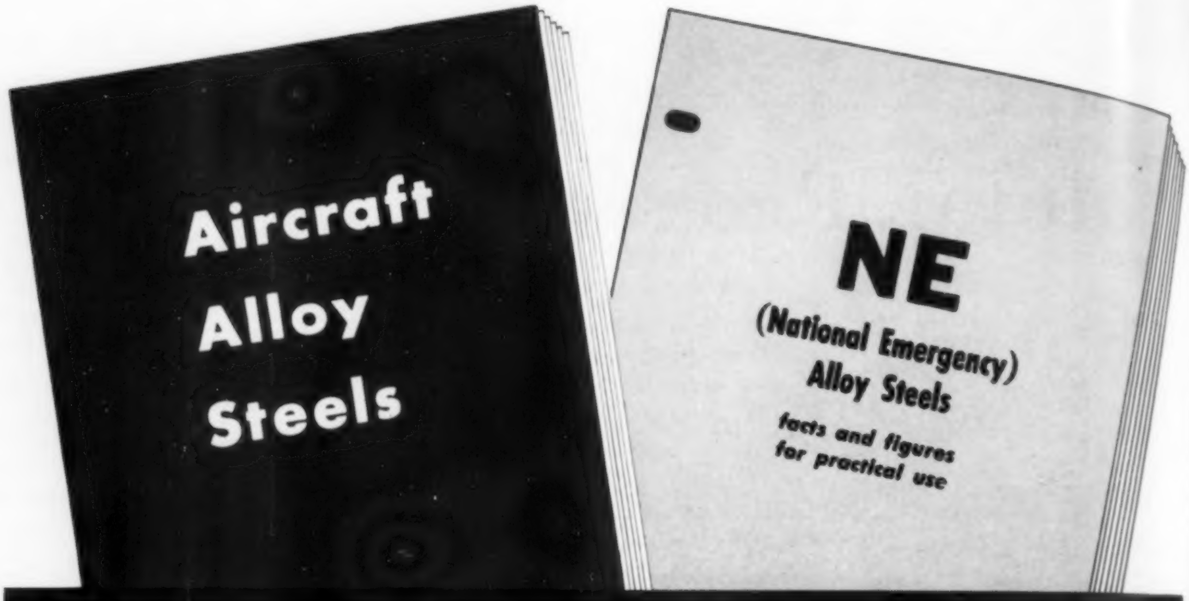

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Supposed Graphite in Carburized NE and S.A.E. Steels

In attempting to associate the results of such accelerated life tests of gears made of NE steels with the metallurgical characteristics of the parts tested, no definite correlation could be found. However, microscopic examination of the extreme surfaces of several of these gear teeth disclosed a grain boundary outlined by a "foreign" material, which — even at 2000 diameters magnification — was not readily identifiable. At first this condition was thought to be prevalent only in parts carburized in compound and made from one particular heat of modified NE9420 steel. (This modified analysis contained 0.30% silicon and was Grainal treated.) It was soon found that parts carburized in gas also showed this "surface attack", but to a much less degree. Random samples taken from gears of other steel types, carburized in regular production, revealed a similar condition and again the gas carburized gears were less affected than those carburized in compound. Rarely did this "foreign" material extend beyond 0.001 in. deep in the common grades of steel with medium case depths.

ON A NUMBER OF OCCASIONS mention has been made of the absorption of oxygen during the carburizing process. As the exact mechanism has never been described in detail, and as the effects are not too well understood, it has never been considered a controlling factor in the production of hard surfaced parts. However, in tests conducted in the laboratories with which both authors are associated, certain facts were uncovered indicating that oxygen produces a physical condition on the surface of carburized parts which undoubtedly influences its behavior when subjected to stresses.

One of the most important uses of the carburizing process, and one in which extensive inspection and testing is done, is in the production of automotive gearing. In these parts much dependence is placed upon the hardness and durability of the surface. When carburizing practices are not of the highest quality the results will be gears of poor performance and short life. While a great deal of proving is done in actual service, the largest proportion of the testing of automotive gearing is done on the laboratory dynamometer, and it has been through such testing that many improvements have been made in carburizing. It is only natural, therefore, that gears made of the National Emergency steels, substituting for the older alloy steels, should be put through the full assortment of laboratory tests.

Simultaneously other observers found this condition in carburizing the regular NE9400 series. Some have considered it to be graphite and have been reluctant to use this new NE analysis for that reason. That this grain boundary condition has accompanied carburized parts of other commonly used low carbon steels was revealed by our additional investigations. The condition, whatever it is, is therefore certainly not confined to any particular analysis of the newer carburizing grades.

The data herein reported are the results of a series of tests designed to determine the mechanism of producing this grain boundary constituent and its identity.

Test Procedure — In attempting to arrive at a solution for this problem, it was considered of fundamental importance to differentiate between *(a)* those factors commonly referred to as "inher-

Table I — Chemical Analysis of Steels Tested

Type	C	Mn	P	S	Si	Al	Cr	Ni	Mo
Armco iron (A)	0.025	0.02	0.005	0.030	Nil	0.005	0.01	0.06	Nil
Armco iron (B)	0.035	0.16	0.011	0.016	Nil	0.035	Nil	0.04	Nil
Rimmed steel	0.24	0.36	0.023	0.030	0.01	0.008	0.06	0.13	0.01
Modified S.A.E. 1010	0.12	0.39	0.020	0.020	0.02	0.034	Nil	Nil	0.12
Modified S.A.E. 1010	0.10	0.35	0.010	0.026	0.03	0.100	(Aluminum killed)		
S.A.E. 1015	0.12	0.46	0.010	0.022	0.23	0.024	0.05	0.17	0.02
S.A.E. 1020	0.20	0.46	0.020	0.036	0.17	0.014	Nil	0.04	Nil
S.A.E. 1040	0.42	0.74	0.014	0.029	0.17	0.005	Nil	Nil	Nil
S.A.E. 2320	0.20	0.57	0.015	0.036	0.27	0.008	0.14	3.51	Nil
S.A.E. 2512	0.12	0.55	0.015	0.025	0.28	0.040	0.23	5.05	0.05
S.A.E. 4120	0.20	0.38	0.009	0.015	0.27	0.021	0.91	0.15	0.23
S.A.E. 4620	0.20	0.65	0.016	0.021	0.23	0.038	0.03	1.83	0.21
S.A.E. 4820	0.17	0.62	0.013	0.023	0.23	0.036	0.08	3.44	0.20
NE 8720	0.23	0.81	0.014	0.023	0.30	0.047	0.48	0.62	0.27
Modified NE 9420 (Grainal added)	0.20	0.86	0.015	0.022	0.30	0.027	0.32	0.35	0.12
NE 9420	0.20	0.99	0.017	0.018	0.43	n. d.	0.28	0.44	0.10
Timken DM	0.10	0.40	0.009	0.010	0.58	0.004	1.19	0.23	0.55
Timken Silmo	0.11	0.19	0.010	0.012	1.37	0.021	0.06	0.21	0.50
Timken Sicromo No. 1	0.15	0.42	0.017	0.016	1.40	0.008	1.27	0.24	0.54
Timken Alcrosil No. 3	0.12	0.36	0.015	0.014	1.04	0.51	2.83	0.23	0.52
Nitralloy G	0.33	0.56	0.019	n. d.	0.26	1.10	1.18	0.16	0.26

ent" properties of the metal as defined by steel chemistry and deoxidation practice and *(b)* the influence of processing conditions subsequent to the melting and shaping of the steel.

A tabulation of the variables considered under these two headings is given below:

I. Carburizing Condition
  A. *Carburizing Media*
    1. Barium energized compound
    2. Calcium energized compound
       (a) Grain size in 1 and 2
    3. Coke base compound
    4. Charcoal base compound
    5. Natural gas
    6. Prepared gas
    7. Steel chips (pseudo carburize)
  B. *Carburizing Treatment*
    1. 12 and 21-hr. cycles
    2. Direct and delayed quench
    3. Oil quenched and water quenched
    4. Direct quenched, reheated, and quenched

II. Steel Analyses
  A. "Commercially pure" iron (Armco)
  B. Normal additions of manganese, aluminum and silicon
  C. Larger quantities of manganese, aluminum and silicon and/or chromium, nickel and molybdenum

The 20 steel types explored by us in this investigation had a wide range of common alloy additions, which made it possible to estimate the effect of the individual alloying element. Also, enough of the popular grades of S.A.E. carburizing steels were included so that a definite correlation between these and the newer analyses could be established. This is most desirable, because it established a reference group of steels, which have had varying degrees of success in applications in the casehardened condition. Tables I and II list the analyses of the various steels and carburizing media.

Not all the steels were subjected to all the tests previously outlined, but in general the samples were carburized for a given period, after which they were either rapidly or slowly cooled to room temperature. Samples for microscopic examination, taken so that the surface to be studied was normal to the carburized surface, were carefully prepared to the extreme edge, either by chromium plating the specimen and mounting in a steel holder tube, or by mounting

Table II — Analysis of Carburizing Media

Solid Compounds						
Code	Ba	Ca	Na	S	Charcoal	Coke
A	9.3	..	0.4	0.2	55	22
B	9.5	..	0.2	0.1	84	..
C	5.2	..	0.3	..	28	45
D	2.9	1.5	0.5	..	34	55
E	7.6	3.3	Nil	0.6	..	Bal.
F	0.3	13.3	Nil	0.9	..	Bal.

Gases (Approximate Average)							
Code	CO	CO_2	O_2	CH_4	C_2H_6	C_2H_4	H_2
G	1	..	1	79	16	1	..
H	20	0.4	..	15	..	..	32
J	20	..	..	2	..	..	40

in a bakelite material impregnated with chrome ore adjacent to the sample edge in question. A polishing technique suitable for *retaining* "foreign" material to the very edge was necessary to enable observation at 2000 diameters under reflected white or polarized light.

Tables III to VI summarize the results of these tests, while Fig. 1 to 8 show typical conditions at the surfaces of several steels.

Discussion of Results

Carburizing Media — A careful inspection of Tables III, IV, and V on pages 892 and 893 reveals that barium-energized compounds have a much greater tendency to produce this grain boundary condition, and a progressive lessening of the effect when the steel is carburized in the calcium-energized compound and in natural gas. It is of primary importance to note that practically *all* of the common grades of steel, such as S.A.E. 4120, S.A.E. 4620, S.A.E. 4820, NE8720 and modified NE9420, had appreciable amounts of intergranular constituent when heated in contact with the several barium-energized compounds, but showed only little of this effect for the 12-hr. period in the calcium-energized material *F* and were almost entirely free of this when carburized in natural gas *G*. The longer carburizing period, as described in Table V, served to accentuate this difference.

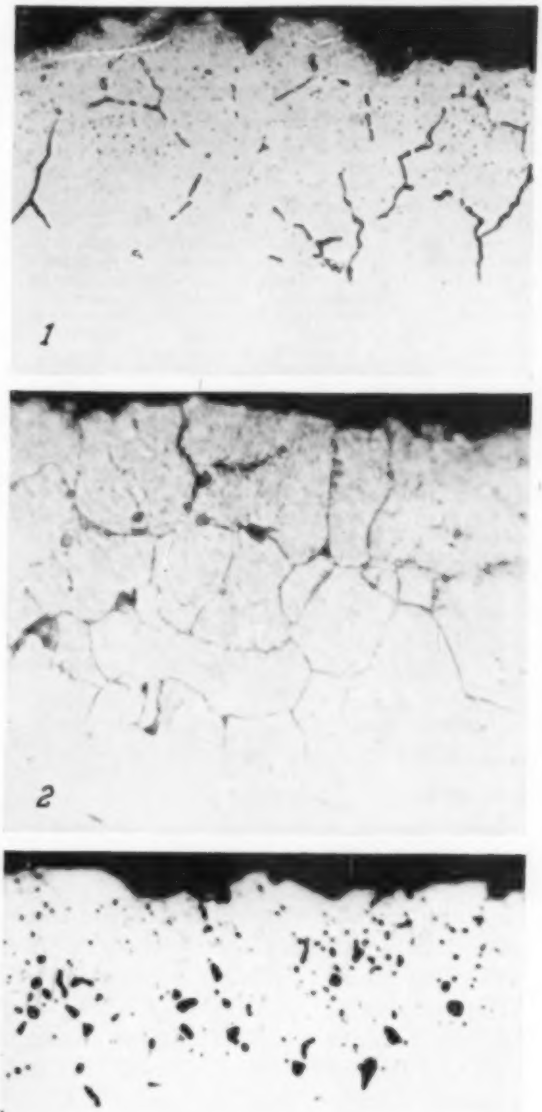


Fig. 1 to 5 — Nature of Attack by Barium-Energized Carburizing Compounds on Commonly Used Steels. Unetched micros (except Fig. 2), photographed at 2000 diameters, reproduced at 1250

Fig. 1 — S.A.E. 1015 in Code E compound
Fig. 2 — S.A.E. 4120 in Code C compound
Fig. 3 — S.A.E. 4620 in Code B compound
Fig. 4 — S.A.E. 4820 in Code A compound
Fig. 5 — NE 8720 in Code E compound

Figures 1 to 5, alongside, illustrate the nature and type of surface attack obtained in some of the commonly used steels. These photographs were chosen as representative of a large number of micrographs obtained with a variety of carburizing conditions, and are not a quantitative evaluation of the relative susceptibility of each steel type to this surface attack.

As is evident from Table VI, the barium-energized and the calcium-energized compounds (Code E and F) differ somewhat in the results produced in the McQuaid-Ehn test. Barium-energized material shows, in several of the different types of low carbon steels, the coarser outlined grain and more susceptibility to abnormality which, according to Grossmann, (⊕ *Transactions,* Vol. 16, 1929, p. 1), indicates a greater absorption of oxygen during the carburizing process.

In order to obtain additional data concerning the effect of oxygen in this problem, a sample of NE8720 steel was heated in an atmosphere known to be oxidizing and with no carburizing tendency — "pseudo-carburization" by packing in oil-free chips of the same steel, and then subjecting this charge to a regular car-

Table III — Tests for Surface Attack

Carburized at 1700 to 1725° F. to produce at least 0.050-in. case depth; direct quench into oil

Type of Steel	Solid Carburizing Compound						Carburized in Gas		
	A	B	C	D	E	F	G	H	J
Armco iron (A)	None	None	None	..	None	None	..	None	..
Armco iron (B)	None	None	None	..	..	..	..	None	..
Rimmed steel	..	..	..	..	None	None	..	..	..
Modified S.A.E. 1010	None	None	None	..	..	..	..	..	..
Modified S.A.E. 1010 (Al killed)	Yes — within the grain	Yes — within the grain	Yes — within the grain	..	Yes — within the grain	None	..	..	..
S.A.E. 1015	Fine network and globular	Network and globular	Network and globular	..	Thick and continuous	Continuous under surface	..	..	..
S.A.E. 1020	Network and globular	Network and globular	Network and globular	..	..	..	..	..	..
S.A.E. 1040	Fine network and globular	Network and globular	..	..	..	..	..	..	..
S.A.E. 2320	Fine network and globular	Network and globular	Network and globular	..	..	..	..	Scattered globules	..
S.A.E. 2512	Fine network and globular	Network and globular	Fine network and globular	..	..	..	..	..	..
S.A.E. 4120	Network and globular	Solid network and globular	Fine solid network & globular	Network & globular	Intergranular & globular	Small particles	Slight network	Scattered globules	Network & [illegible]tered [illegible]
S.A.E. 4620	Network and globular	Network and globular	Fine solid network & globular	Network & globular	..	..	Slight network	..	..
S.A.E. 4820	Solid network and globular	Network and globular	Network and globular	Globular	..	..	Slight network	..	..
NE8720	Network and globular	Network and globular	Fine solid network & globular	Globular	Intergranular	Globular	Slight network	Network of small globules	Network & [illegible]tered [illegible]
Modified NE9420 (Grainal added)	Network and globular	Network and globular	Fine solid network & globular	Globular	Thin grain boundary	Globular	Slight network	Network of small globules	Fine solid net-work & [illegible]
NE9420	..	..	Fine solid network & globules	..	..	..	..	Fine solid network & globules	Network & [illegible]tered [illegible]
Timken DM	..	..	..	.	Thick grain boundary	Globular	..	..	..
Timken Silmo	..	..	..	..	Thick grain boundary	Globular	..	..	..
Timken Sicromo 1	..	..	..	..	Grain boundary	Globular	..	..	..
Timken Alcrosil 3	..	..	..	..	"Chicken tracks"	Small particles	..	..	..
Nitralloy G	Needles and globular	Needles and globular	Needles and globular	..	..	..	..	..	..

burizing cycle. The specimen so treated was examined to the extreme surface (Fig. 7, page 894) and found to contain an intergranular constituent similar to that noticed in carburized samples. Since the surrounding atmosphere in this test was oxidizing in character, we again have reason to suspect that the surface attack during carburizing was related to the presence of oxygen in one form or another.

Hence, these first considerations lead to the obvious conclusion that even though one steel may be more susceptible to this surface attack than another, the carburizing medium certainly has a profound effect. From a theoretical standpoint it is apparent that the carburizing medium probably can be so chosen that a minimum amount of this grain boundary condition will occur at the extreme surface — at least with a medium case depth.

Carburizing Treatment — Also worthy of emphasis is the fact that a longer carburizing period produces a measurably greater surface condition when using a compound such as the barium-energized material. Three of the steels previously mentioned (S.A.E. 4120, NE8720 and modified NE9420) yielded "foreign material" to about twice the depth in 21 hr. as in the 12-hr. carburizing period. This associates the produc-

Table IV — Carburizing Tests at 1700° F. for 0.050-In. Case

(Solid compound, 12 hr. carburize; Gas, 6 hr. carburize plus 3 hr. diffusion; All oil quenched)

Type of Steel	Code E Compound (Barium-Energized)			Code F Compound (Calcium-Energized)			Code G Natural Gas	
	Surface Attack		Case Structure (a)	Surface Attack		Case Structure (a)	Surface Attack	Case Structu[illegible]
	Depth	Remarks		Depth	Remarks			
S.A.E. 4120	0.0003	Globular	0.0005-in. skin. A + M	<0.0001	Only in spots	No skin. A + M	Slight network	No skin. M
NE8720	Approx. 0.0002	Thin grain boundary	No skin. A + M	<0.0001	Only in spots	0.0005-in. skin. A + M	Slight network	No skin. A + M
Modified NE9420	Approx. 0.0002	Thin grain boundary	0.0005-in. skin. A + M	<0.0001	Only in spots	Skin. 0.001-in. ± A + M	Slight network	No skin. M

(a) A means austenite; M means martensite.

Table V — Carburizing Tests for Thick Cases

(Carburized at 1700° F. for 21 hr. to produce approximately 0.070 to 0.090-in. case; Oil quenched)

Type of Steel	Code E Compound (Barium-Energized)			Code F Compound (Calcium-Energized)		
	Surface Attack		Case Structure *(a)*	Surface Attack		Case Structure *(a)*
	Depth	Remarks		Depth	Remarks	
Armco iron	None	..	..	None	..	..
Rimmed steel	None	..	..	None	..	..
Modified 1010 (Al killed)	Slight	Within grain	..	Nil	..	..
S.A.E. 1015	0.0004 to 0.0005 in.	Thick, continuous	Skin. 0.001 in. ±. A + M	0.0003 in.	Continuous under surface	0.001-in. skin. A + M
S.A.E. 4120	0.0008	Intergranular and globular	0.0015-in. skin. A + M + C	0.0001	Small particles	0.001-in. skin. A + M
NE8720	0.0004 to 0.0006	Intergranular	Skin. 0.001 in. ±. A + M	0.0002	Globular	0.001-in. skin. A + M
Modified NE9420	0.0004 to 0.0005	Intergranular and globular	0.0015-in. skin. A + M	0.0001	Globular	0.001-in. skin. A + M
Timken DM	0.0005	Thick grain boundary	Skin. 0.001 in. ±. A + M	0.0002 to 0.0003	Globular	0.001-in. skin. A + M
Timken Silmo	0.0005 to 0.0007	Thick grain boundary	0.001-in. skin. A + M + C	0.0003	Globular	0.001-in. skin. A + M + C
Timken Sicromo 1	0.0008 to 0.001	Grain boundary	0.001-in. skin. A + M	0.0002 to 0.0003	Globular	0.001-in. skin. A + M
Timken Alcrosil 3	0.0002 *(b)*	Chicken tracks *(b)*	0.001-in. skin. A + M	0.0001 to 0.0002	Small particles	0.001-in. skin. A + M
Nitralloy G	0.0066	Needles and globular	A + M	..	..	..

(a) A means austenite; M means martensite; C means carbides.
(b) "Chicken tracks" to a depth of 0.002 to 0.003 in.

tion of the intergranular material with the actual time at carburizing temperature rather than with any reaction occurring during the heating up or cooling process.

To further substantiate the independence of this surface manifestation from the method employed in cooling the carburized part, additional tests were conducted: Four specimens of the modified NE9420 steel were carburized for 21 hr. in a barium-energized compound and each cooled in a different manner. In two instances, after the heating cycle was completed, the carburizing container was suspended directly above the oil and water quench tanks, respectively, and samples were quenched as rapidly as possible, thus exposing hot steel to the air for a minimum time (approximately ½ sec.). By contrast, samples from the same container were given a "delayed" quench by exposing them to the air for 30 sec. before oil and water quenching, respectively. There was no detectable difference in the carburized surface of these samples when viewed at high magnification, thus emphasizing that the surface attack took place *prior* to the removal of the steel from the carburizing compound.

The possibility of eliminating this relatively thin surface layer by an additional heat treatment after carburizing and direct quenching was also

Table VI — McQuaid-Ehn Grain Size

Type of Steel	Code E Compound (Barium-Energized)		Code F Compound (Calcium-Energized)	
	Grain Size	Abnormality	Grain Size	Abnormality
Rimmed	..	..	2 to 4 (1)	Abnormal
S.A.E. 1015	..	..	6 to 8	Normal
S.A.E. 4120	6 to 8 (4)	Normal	6 to 8	Normal
NE8720	6 to 8 (5)	Slightly	6 to 8 (5)	Normal
Modified NE9420	7 to 8 (6)	Slightly	6 to 8	Normal
Timken DM	No carbide network	..	No carbide network	..
Timken Silmo	No carbide network	..	No carbide network	..
Timken Sicromo No. 1	No carbide network	..	No carbide network	..
Timken Alcrosil No. 3	No carbide network	..	No carbide network	..

Fig. 6 — S.A.E. 4120 Carburized in Code F Compound (Calcium-Energized). Unetched, at 2000 diameters

considered. If the grain boundary matter was a precipitate which became insoluble during the cementation process, an additional heating and cooling in the absence of a carburizing atmosphere might alter the pseudo equilibrium sufficiently to redissolve some or all of this constituent. This, however, was not found to be true. Samples carburized for 21 hr. in the barium-energized compound, direct oil quenched, reheated to 1550° F. in a NaCl-KCl salt bath, and again quenched in oil, showed no visible difference in the type or relative amount of surface grain boundary material from companion samples merely carburized and oil quenched. (Bear in mind that the reheating operation as carried out in this test prevented any scale formation which could easily have "eliminated" the surface condition by removing the layer of steel being studied.)

Steel Analyses — Now focusing attention on the actual composition of the different steels tested (Table I), and the results after the various carburizing treatments in both barium and calcium-energized compounds (Tables III and V), a very definite correlation is seen to exist. A sharp line of demarcation can be drawn between those steels which contain an appreciable amount of silicon and those without. In each of the steels having more than an incidental amount, the carburized surface is attacked, while none of the steels substantially free of silicon showed this phenomenon with either barium or calcium-energized compound.

Armco iron was entirely free of attack, even after carburizing in the rather active compound Code E. It is to be noted, however, that the low silicon and relatively high aluminum composition (modified S.A.E. 1010, Al killed) had a nonmetallic material in random distribution near the surface. Also, the carburized nitralloy sample (Fig. 8) contained needles and globules in a random distribution to a depth several times greater than that found in any of the carburizing grade steels. While the precipitate in nitralloy is not a grain boundary condition, it is of significance and later it will be shown how the two manifestations are related.

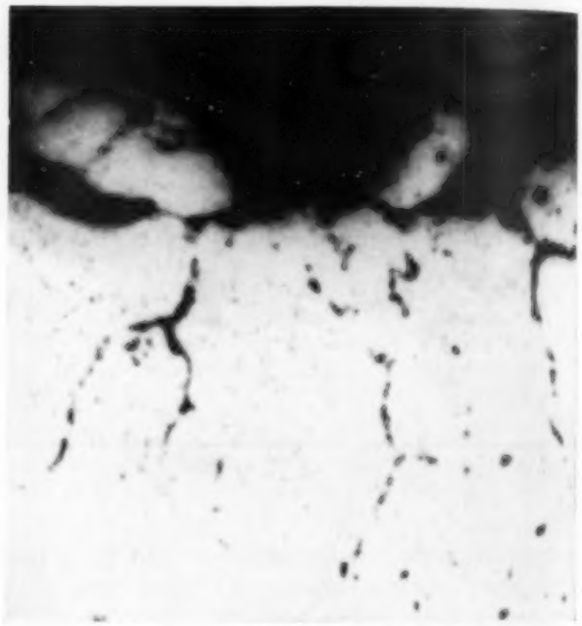


Fig. 7 — NE 8720 Pseudo-Carburized by Going Through Regular Carburizing Cycle, Packed in Degreased 8720 Chips (2000×)

Typical examples of these differences in the way silicon content is related to the surface attack are shown in other micros. Hence the inevitable conclusion is that the elements silicon and aluminum either promoted a chemical reaction in one or more of the constituents within the steel, or themselves entered into such a reaction with an element or compound brought to the steel's surface during the carburizing treatment.

The first of these two possibilities immediately suggests that cementite may be decomposed near the surface, since silicon and aluminum are known to promote graphitization. However, a scrutiny of the various compositions tested reveals four reasons why this deduction is highly improbable:

1. The S.A.E. 4120 specimen (Fig. 2) which varied in composition from the S.A.E. 1015 and 1020 grade primarily in the additional amount of carbide-stabilizing chromium, contained a very definite grain boundary constituent to a depth

similar to that obtained in the other carburizing grade steels.

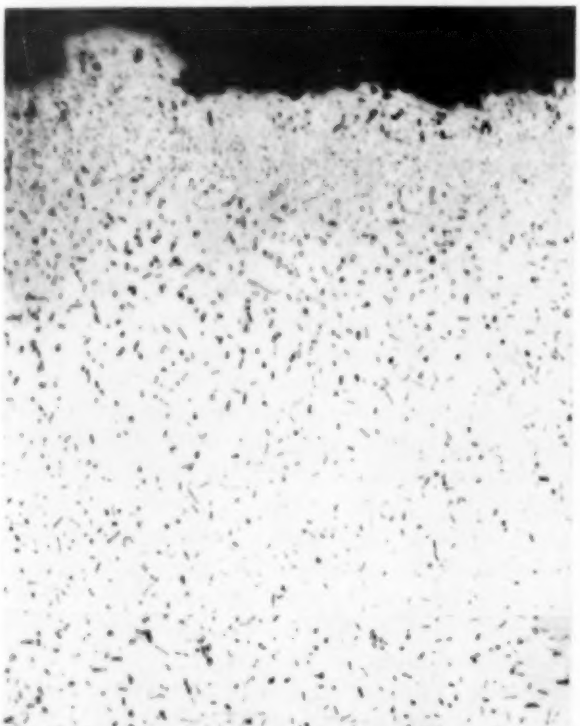
2. Failure to show a marked difference in the results on the Timken Silmo, indicates that the more than five-fold increase in silicon content over the other carburizing types was ineffective in increasing the surface condition in question.

3. When comparing results of the Timken DM analysis with Timken Sicromo No. 1 (practically the same composition except for the much greater silicon content) only minor variation was recorded. This is contrary to what would have happened if silicon had actually made the carbides unstable.

4. When specimens containing this grain boundary constituent were reheated for a prolonged period in a decarburizing salt bath, no noticeable change was recorded in the appearance or amount of intergranular material.

Thus, ruling out the possibility that the carbide of the steel is disintegrating, the next most likely cause for the grain boundary condition is the reaction of silicon and aluminum with some material at the steel's surface. In fact, microscopic examination of some of these well polished particles with both reflected white and polarized light indicated them to be not graphite but a silica glass of some type impregnated with a small amount of gray, anisotropic substance answering the description of alumina. While this cannot be taken as a positive identification, it must be considered as strong supporting evidence that silicon (and minor amounts of aluminum) is part of the compound in the grain boundary.

Fig. 8 — Nitralloy G, Carburized in Code C Compound; Unetched; Magnified 1000 Diameters



Further identification was attempted by the chemical etching procedure for inclusions in the Metals Handbook. This method consists of polishing and etching with specific reagents until one is found which attacks and chemically removes the substance under observation. In these specimens, no reaction developed until the 20% hydrofluoric acid was used. This etchant removed all of the grain boundary constituent, and some particles within the grain of several of the steels tested. These results are additional confirmation that the grain boundary constituent is a silicon compound.

Origin of the Non-Metallic Compound

Having established that the grain boundary precipitate is a compound containing primarily silicon and aluminum, a plausible explanation for its occurrence may be presented:

As is well known to steel makers, silicon is a potent deoxidizer, exceeded only among the common additions by aluminum, which has a still higher affinity for oxygen. If, in the carburizing process, oxygen is carried to the steel's immediate surface, it is therefore conceivable that a union of oxygen and silicon and/or aluminum would take place at the solid-gas interface.

Exactly such an opportunity exists in pack carburizing where carbon from the solid compound is made available to the hot gamma-iron solution through the medium of carbon monoxide gas. Depending upon the exact carburizing conditions and the temperature employed, the concentration of CO in the gas contained in the pot or muffle ranges from 95 to 98% during the entire carburizing period. This is maintained by a regenerative action with the hot, solid carbon of the coke or charcoal (which is in equilibrium with the gas and steel) by the following familiar chemical reactions:

$$2C + O_2(\text{Air}) = 2CO \qquad (1)$$

$$3Fe + 2CO = Fe_3C + CO_2 \qquad (2)$$

$$CO_2 + C = 2CO \qquad (3)$$

Reaction shown by equation (1) takes place until equal thermal conditions are reached, after which reactions (2) and (3) are in operation. These reactions mean that carbon monoxide, in the presence of iron at carburizing temperatures, gives up half of its carbon to the iron and forms carbon dioxide with the remainder, which in turn is reverted back to carbon monoxide by the hot, solid carbon. All of the above statements refer to accepted facts and constitute nothing new.

However, equation (2) can be rewritten in the following way:

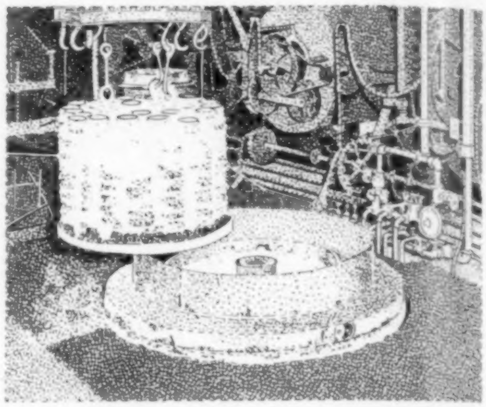
$$\begin{array}{l} Fe \\ Fe + C\,O = Fe_3C + CO_2 \qquad (2a) \\ Fe \quad\; CO \end{array}$$

This means that while two molecules of CO enter into the reaction, only one gives up its carbon to the iron, momentarily releasing one nascent oxygen atom — presumably to combine with the other unaffected CO molecule. Since there is some solubility of oxygen (or carbon monoxide itself) in hot steel, it can come in very intimate contact with other elements in solution which have a high affinity for oxygen, such as silicon and aluminum. Since both of these latter elements are in solution in austenite and thus are free to diffuse at a definite rate, it is most probable that reaction (2) is not the only one involved. The laws of physical chemistry suggest that the following reactions also take place, the extent of which are dictated by factors which we cannot at present evaluate:

$$4CO + Si + 9Fe = SiO_2 + 3Fe_3C + CO_2 \qquad (4)$$
$$5CO + 2Al + 12Fe = Al_2O_3 + 4Fe_3C + CO_2 \qquad (5)$$

Why silicon forms the grain boundary constituent and aluminum yields a random distribution (as in nitralloy) is not clear. However, a review of the data presented in this article, keeping in mind the chemistry of each type of steel, illustrates the difference both in type and quantity of inclusion produced by silicon and aluminum.

Assuming that the above deductions are essentially correct, the reason that samples carburized in natural gas (Code G carburizing medium) show considerably less surface attack is easily understood. One must only recall that it consisted primarily of hydrocarbons and contained but 1% CO and 1% O_2 (subsequently converted to CO), which apparently supplied only limited quantities of nascent oxygen for reactions (2), (4) and (5). It also follows that other gas compositions should produce this surface effect in some relation to the percentage of contained CO. No explanation can be offered for the marked difference between the barium-energized and the calcium-energized compounds, other than a "catalytic" effect.



Conclusions

1. The nature of the carburizing medium was found to be important in determining the extent of the grain boundary attack in any given analysis of carburizing steel.

2. Under those conditions in which surface attack did take place, *(a)* a longer carburizing period yielded a more prolific condition, *(b)* direct or "delayed" quench in either oil or water showed no change, and *(c)* subsequent heat treatment was ineffective in erasing an existing condition provided the surface layer was not scaled off.

3. Appreciable amounts of silicon in the steel, within the range specified for S.A.E. and NE types, produced a grain boundary precipitate at the surface while a greater-than-normal content of aluminum was required before a random distribution of a non-metallic constituent in the carburized zone could be detected. These results emphasized that this surface condition is not exclusively associated with the higher silicon NE9420 type steel.

4. There are several reasons why this material probably is not graphite.

5. Both microscopic and chemical methods indicated that the grain boundary constituent is a silica and alumina mixture formed during carburizing. Theoretical considerations were developed as an explanation for this chemical behavior in a so-called reducing atmosphere.

Acknowledgments — The writers wish to express their gratitude to those who have taken an active interest in the development of this problem. They are especially thankful to R. H. Marshall of the Timken Roller Bearing Co. and to F. E. Johnson and B. McGiverin of The Timken-Detroit Axle Co., who cooperated to obtain the experimental data.

Cartridge Brass

(an elementary introduction)

By L. E. Gibbs
Technical Advisor, Rome Division
Revere Copper and Brass, Inc.
Rome, N. Y.

THE ALLOY OF 70% copper and 30% zinc, commonly known as cartridge brass or 70-30 brass, is a versatile member of the brass family. Perhaps the title is as descriptive as any that could be devised to describe its properties briefly —namely, a brass alloy of high strength and ductility, capable of deep drawing. This and following articles will discuss some of the properties of the alloy and the means to control these properties. However, before proceeding, it might be well to review some of the basic facts concerning the brasses, as well as some of the terms and methods employed to measure their properties.

Cartridge brass is a single-phase alloy containing all alpha brass just like the rest of the copper-zinc alloys containing about 65% copper or more. Because they are single phase of the alpha type, they cannot be heat treated to increase strength and hardness. The only manner in which physical properties may be varied is by cold working or by annealing. By "cold" is meant the ordinary room temperatures encountered in fabricating brass, as contrasted to hot working which usually means, for copper-zinc alloys, between 1200 and 1600° F.

In the drawing or fabrication of a cartridge case, or any other similar article, the cold forming process increases the tensile strength and hardness but at the same time decreases its ductility and toughness, an action typical of many metals. As in other materials, there is some point in the cold forming process at which ductility is no longer sufficient to allow further deformation. Hence, annealing or softening is required before further reduction can proceed. The extent to which the softening or annealing takes place is dependent upon the amount of previous cold deformation and time plus temperature. Consequently, the cold working and annealing relationships go hand in hand and one cannot be changed indiscriminately without affecting the other.

It is important in setting up the cold working and annealing cycles that the proper relationship be established to meet the properties required, either in cartridge cases or other articles. In order to maintain the fastest production rate and the highest quality, this ratio should be held within the necessary limits. Later discussion will describe briefly the limits indicative of those required. The operating limits must be established by experimenting with the actual equipment at hand.

Hardness Designations

It might be well also to review the methods used to describe cold working and annealing and their extent. It is the custom in the copper and brass sheet and strip industry, particularly, to refer to cold rolled (reduced) metals by the terms

Table I — Classification of Cartridge Brass by Cold Work

Temper Designation	Nominal Reduction B&S Gage No.	Per Cent Reduction (Approx.)	
		Sheet & Strip	Rods, Round Shapes, Etc.
Quarter hard	1	10.9%	20.7%
Half hard	2	20.7	37.1
Three-quarter hard	3	29.4	50.0
Hard	4	37.1	60.5
Extra hard	6	50.0	75.0
Spring	8	60.5	84.4
Extra spring	10	68.7	90.2

"quarter hard", "full hard", "spring hard", etc. In Table I their meaning is shown in relation to the Brown & Sharpe gage system. This gage system is based upon a constant percentage-difference between gage numbers, and it consequently follows that there is also a constant difference between any two given gage numbers the same number of digits apart. That is to say, the per cent difference between 10 and 14 B&S gage numbers is the same as between 22 and 26 B&S gage numbers.

Practically speaking, this difference in gage numbers also represents an amount of cold reduction — for strip a reduction in thickness, and for rounds a decrease in area. Consequently, the term "quarter hard", as an example, means a cold reduction, from an annealed state, of 1 B&S number to final thickness. Obviously, with a given alloy, it also means definite physical properties (within commercial limits). Hence, the terms in column one of Table I are definite descriptions of physical properties of 70-30 brass and are so used in this article as well as by the trade.

Thick plates and similar heavy gage metal are not within this category, since mill equipment is not capable of the cold reductions required.

It will be noted that the last column is headed "Rods, Round Shapes, Etc." These figures are based on *area* difference, and are used, as the title denotes, for round shapes particularly; it is important to note that the amount of reduction for 4 numbers is not the same for a round section as it would be for strip. It is preferred practice in our plant to use, when speaking of rounds, the *percentage* reduction of cold working rather than a number, because of the greater accuracy of this description.

In summation, the larger the cold reduction, or greater the "numbers hard", the greater is the tensile strength, hardness and, at the same time, the lower the elongation and reduction in area (the extent of change depending upon the alloy).

Table II — Classification of Grain Sizes

Nominal Grain Size	Typical Use
0.015 mm.	Slight forming operations.
0.025	Shallow drawing (automobile hub caps).
0.035	Best average surface after cold working (automobile head lamp reflectors).
0.050	Average drawing operations.
0.100 and greater	Heavy draws — thick gages.

Ductility Regulated by Grain Size

Annealing, on the other hand, uses a system which describes in millimeters the average diameter of the crystals after heat treatment, commonly known in the trade as "grain size". The

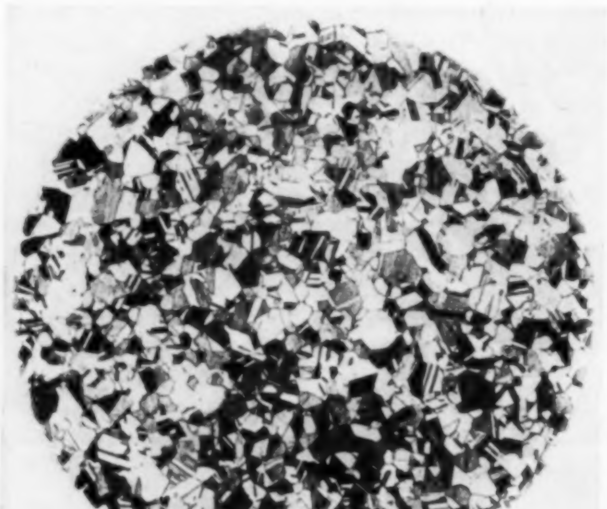


Fig. 1 — Grain Size 0.035 Mm.

Fig. 2 — Grain Size 0.090 Mm.

Annealing Processes Are Regulated by the Grain Size of the Product, Which as Shown Above Can Vary Within Wide Limits. Recommended practices for determining grain size are given in Specification E2-39T of the American Society for Testing Materials. See also data sheet in Metal Progress, 1941 Reference Issue (October), page 432

best description of the value and the actual sizes may be seen in the standards of the American Society for Testing Materials. The charts furnished in these standards show the actual size of the crystals at the usual magnification of 75×. Table II tabulates commercial designations of ranges and types of familiar articles in these various classifications, which would be applicable to 70-30 brass — or a similar alloy, deep drawing brass (67% copper, 33% zinc nominal analysis). Figures 1 and 2 indicate actual grain sizes at 75× for typical classes, 0.035 and 0.090 mm. respectively.

It is obvious that the larger the grain size the softer the metal, which is shown by lower tensile strength and increasing elongation and reduction of area. Within commercial limits of furnaces and annealing equipment, there are definite minimums and maximums which can be obtained. These will be discussed later.

In reference to cartridge brass and its particular metallurgical properties, increasing the zinc content of a red brass will increase the strength and also increase the ductility up to the approximate composition of cartridge brass; above this point the ductility starts to decrease but tensile strength continues to increase. In effect, this means that the ratio between the ductility and tensile strength is at its highest, which is quite important in the fabrication of cartridge cases or other difficult deep drawing articles. Modern cartridge cases, especially some developed in the course of World War II, represent extremes of difficulty which are met but rarely in ordinary peacetime production. It is in the production of some of these cases that the properties of tensile strength and ductility are most important.

To over-simplify the problem, in the course of drawing with a die and a mandrel there are forces which are exerted to distort the metal into a new shape and, at the same time, stress the metal very considerably. Hence, an alloy which will successfully cold deform must be strong enough to resist the tensile or other stresses tending to fracture, as well as be ductile enough to conform to the new shape being produced.

General Properties of 70-30 Brass

Among all of the brasses, 70-30 has this combination to the greatest degree, which explains why it is specified particularly for cartridge cases (copper content 68.5 to 71.5% in most Government specifications). This allows operations which are nearly the minimum in number, for producing a given part with the fewest pieces of mechanical equipment and in-between anneals.

These properties also are important in the actual use of the case itself, as those familiar with the problem well know.

The increase in strength with increasing copper content is shown in Fig. 3, which is self-explanatory. The figures shown are only approximate; they are for annealed material and intended as a guide rather than for absolute values.

It should be noted also that as the copper content changes, the effect of temperature after cold working also changes. That is to say, for a given annealing temperature an increase in content of copper means that a larger grain size will be obtained. However this remark applies to the alpha brasses as an entire family — chemical specifications for a particular member of the family, such as cartridge brass, are written so that the grain refinement and growth under a given set of physical conditions will be reproducible. Variations in cold working and annealing cycles will cause a far greater difference in grain size than fluctuations in copper content, within the specified limits. (Since beta brass appears within the range of copper content of 58 to 63, approximately, crystals of beta tend to obscure the actual grain size.)

Forming a Cup From a Flat Sheet or Strip Is a Searching Test of Metal's Quality

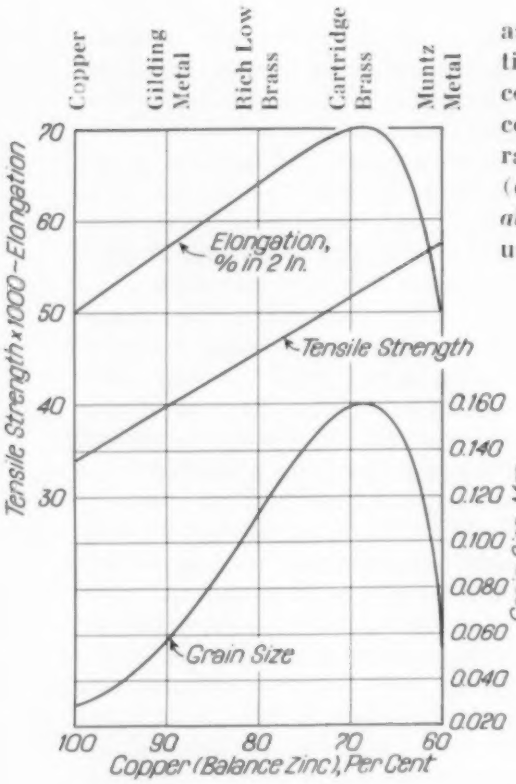


Fig. 3 (left)—General Influence of Copper Content on Properties of Annealed Brass

The specific properties of 70-30 brass are shown in Fig. 4 and 5, representing the effects of cold working and annealing, respectively.

Figure 4 notes the increase in tensile strength, "apparent elastic limit", and Rockwell hardness as cold working (in terms of B&S numbers) increases. (The apparent elastic limit is a point above which increase in strain is no longer at the same rate as increase in stress. Value is generally conservative and most times lower than the 0.5% yield point.) This effect is typical for copper-zinc alloys of the alpha type except that those with lower copper content tend to "level off" as the cold working reaches the range of 8 and 10 numbers hard, and a very definite maximum (considering commercial equipment) tends to be reached. The *absolute* maximum depends on the shape, which commercially is usually reached in the form of wire.

Figure 5, indicating the change in properties due to the application of heat, is predicated upon a given amount of cold working prior to the application of heat. This relationship will be discussed in a later article.

Commercial practice on cold rolled (cold worked) material will range from extremely slight amounts for very special uses up to and including the tempers between 8 and 10 numbers hard in strip form. In rod and tubular form these heavy reductions cannot be achieved, as a rule. Annealed metal grain sizes vary somewhat according to gage and, as Table II notes, most light gage metal is furnished with grain sizes varying between 0.010 mm. and 0.050 mm. As the gage increases and the severity of the operation increases, the grain sizes are considerably larger. The material going into cartridge cases will be in excess of 0.055 mm. — a grain size seldom used in peace times. It is difficult to define, exactly, "light" gages and "heavy" gages, but light gages, commercially, will mean somewhat less than 0.075 in. and heavy gages over 0.075 in. It should be noted that the relatively heavy material — over ¼ in. — being used for certain types of cartridge cases represents practice and does not represent the largest peacetime uses. The lighter gages with resulting smaller grain sizes are in more general use, largely because of surface effects to be discussed later.

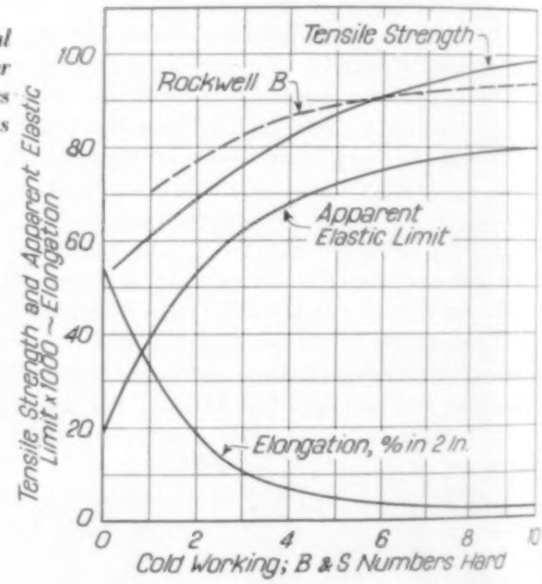


Fig. 4 (right) — Influence of Cold Rolling on Cartridge Brass Strip

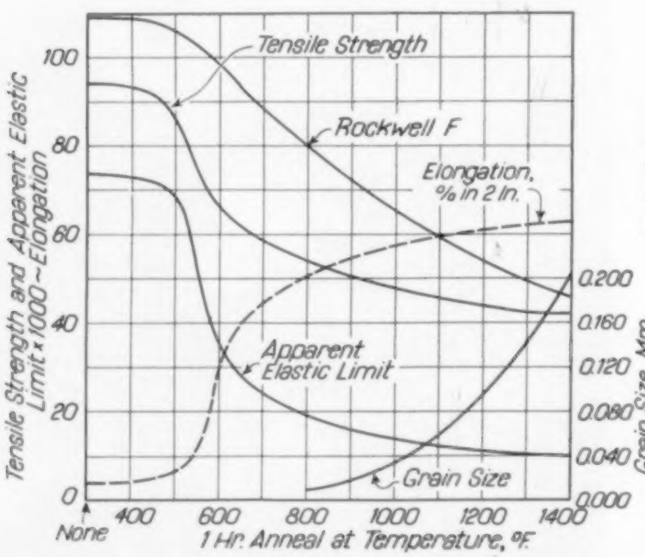


Fig. 5 — Physical Properties of 70-30 Cartridge Brass, Cold Rolled 6 B&S Numbers Hard, Then Annealed 1 Hr. at Various Temperatures

Openhearth Men Discuss Their Wartime Problems

Reported by
H. J. Forsyth
Mill Metallurgist
Republic Steel Corp., Buffalo, N. Y.

THE NATIONAL OPENHEARTH COMMITTEE of the American Institute of Mining and Metallurgical Engineers met in Cleveland last month for its 26th annual conference, with the purpose of discussing methods for sustaining current production rates in the face of problems which have arisen from wartime conditions. With able guidance from LEO F. REINARTZ, chairman, 651 operators and technicians gave well-balanced attention to 33 subjects, so the conference provided a thorough survey of existing practices and problems.

Rapid Furnace Repairs

Operators discussed the rebuilding of furnaces with more illustrations and details than in previous years. The fact that some reported complete rebuilds in 66 hr. for 175-ton furnaces and 38 hr. for 70-ton furnaces indicates the speed which has been made. Tractors are being used increasingly to tear down and remove brickwork with resultant savings in labor and time. Cleaning of slag pockets has been expedited by dragging out the accumulated material in one piece, thus: A heavy billet resting on a fulcrum is rammed under slag in the pocket and a load, such as a ladle full of old bricks, is lowered on the free end of the billet, raising the entire slag chunk enough so that chains can be placed around it. The chain is attached to a strong cable which is anchored securely at its other end across the building and looped over the hook on a ladle crane. By raising the crane hook the chunk can be pulled out intact. Further economies in rebuilds and maintenance come from the use of rammed bottoms which appear to be generally accepted and approved. On the other hand, reports concerning basic roofs were unfavorable.

Heavy Oil Is Best Fuel

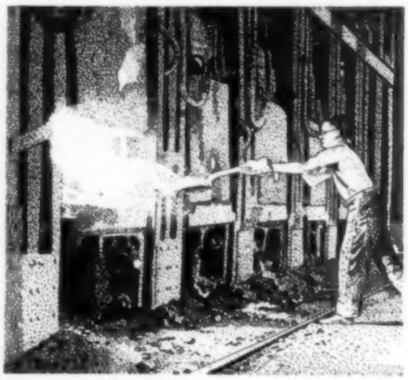
Producers were emphatic in stating that "cutting" low gravity fuel oil with lighter grades produced no true economy. Cut-fuel has been found to lower production rates and increase maintenance delays; because lower pressure must be used, more gallons are required per ton of steel melted. It was reported that a change from oil to natural gas lost 10% in steel production rates. Education of furnace operators and provision of proper fuel controls appear to be the most practical methods of conserving oil, and a marked increase in automatic furnace control installations during 1942 indicates that steps are being taken in these respects.

Much Light Scrap Remelted

Due to increased blast furnace capacity and anticipated larger supplies of home scrap the raw material (scrap) situation will be less critical during the coming year. However the War Production Board will not relax its efforts to obtain scrap from civilian sources so adequate reserves can be assured. Furthermore, it was predicted that at least half of the purchased scrap will consist of turnings and borings. This led to discussions concerning their use in openhearth charges and it became evident that utilization of such materials is one of the most serious current operating problems.

Turnings now contain from 5 to 15% oil by volume, and are responsible for the deterioration of furnace refractories. Since many steel mills are using 10 to 20% turnings in the openhearth charge, trouble has also resulted from flue dust.

However, it was unanimously agreed that the widely varying analyses encountered within a single car or shipment of turnings caused the most serious difficulties. Several operators have found bessemer, plain carbon and alloy steels (or even bearing metals) in the same car, and although thorough sampling has spotted such mixtures and aided in their separation, it has not greatly reduced the current problems. Unanticipated alloy or sulphur residuals in the charge mean changes in production schedules, delays in operations, waste of recoverable alloys, and presence of undesirable elements in the finished steel which may seriously affect its properties. In addition, the W.P.B. is holding steel mills strictly accountable for the recovery of alloys in scrap, and since turnings will be used increasingly during the coming year, they must be more carefully segregated by suppliers if the alloying elements are to be conserved. It was felt that the machine shops and fabrication plants must be more thoroughly educated in the proper segregation and cleaning of such material. At the same time operators were told that much remains to be done in the segregation of home scrap.



To assure maximum recovery of alloys from turnings or borings, one producer charges them into the blast furnace on special runs, so pig iron or hot metal of known alloy content is obtained. This appears to have interesting possibilities, especially in melting shops producing large tonnages of alloy grades. Other plants are shredding and centrifuging loose turnings; the oil content may thereby be reduced from as much as 55 gal. to 1 or 2 gal. per ton, and material which weighs 10 to 12 lb. per cu.ft. is concentrated to approximately 30 lb. per cu.ft. Briquetting is also being adopted in various plants; turnings are first washed with hot water, hydraulically compressed to remove oil and then fed into the briquetter. Any remaining oil is subsequently burned off by passing the briquettes through a continuous furnace operated at 1500° F., the operation being controlled so that oxidation is kept to a minimum. It was felt that resulting economies in handling and furnace costs defrayed the expense of this procedure, but emphasis was placed on the fact that briquetting by no means reduces the necessity for careful segregation of waste material by analysis at the source.

Manpower — and Women Steelworkers

Wartime difficulties were further reflected in a discussion of personnel problems. With steadily decreasing manpower reserves, attention is being given to employment of women. Although the number of women employed for openhearth work varied widely in representative shops, it was generally agreed that they were being used successfully for recording and for some types of common labor. Several employers reported favorable experience with women in mason gangs, but few have used them for crane-men or furnace helpers. Due to the highly competitive labor market, more than normal efforts are being made to improve working conditions and to bring about closer personal contact between employees and supervisors. Foremen are considered to be the most important agents in maintaining cordial relations with employees, and at present several producers conduct special training courses for them.

Earle C. Smith gave some interesting details, learned on a recent visit to English steel mills. At present 13% of the employees over there are women, some of whom are being used for heavy work, others for highly skilled work such as blooming mill rolling. The conference was warned that American mills soon may be forced to follow this example. He also stated that blackouts of steel plants in England have been highly successful, and the fact that blackout equipment is inspected four times on each shift indicates the attention given to details.

Production of NE Steels

Technicians and operators compared notes on the manufacture and properties of NE steels. As is well known, these grades were developed to replace conventional alloy steels so that reserves of virgin alloying elements could be maintained. They have proved entirely satisfactory when produced with the same care that was given to grades they replaced. A check of practices showed that the production of NE steels permitted no relaxation in quality controls. Most grades require slow cooling after rolling to prevent flaking. Charles H. Herty reported that the War Production Board was anticipating heavy demands for the NE9400 series which specify 0.08 to 0.15% molybdenum, and expects operators to recover 75% of the final alloy content from scrap — a fact which further emphasizes the necessity for careful segregation of scrap. Maximum utilization of molybdenum contained in scrap will become one

of the most important alloy problems, since molybdenum is becoming scarce.

The record demands for high quality steels directed full attention to technical discussions. E. C. WIGFIELD won the McKune Award for a paper describing production of NE1330 steel in 50-ton basic furnaces. It had been the usual practice to make this grade with a block of 15% silicon pig iron, so that large additions of ferromanganese were necessary. Since the heat had to be taken low in carbon to permit this, the ladle analyses were erratic and quality suffered from the chilling effects of large manganese additions. By blocking with silicomanganese these undesirable conditions were minimized, and the quality and chemistry were greatly improved. Education and training of melters and first helpers in the new technique was the most difficult problem encountered in this change of practice.

To meet the specification of 0.28 to 0.33% carbon and 1.60 to 1.90% manganese, Mr. WIGFIELD stated that the bath should analyze 0.18% carbon and 0.30% manganese, while total Fe_2O_3 in the slag should approximate 17% when the heat is blocked. At that time 1000 lb. of silicomanganese is added to the bath and the fuel is left on the furnace for 5 min. under 80 lb. of steam pressure. Fuel is then shut off for 10 min. to stop any action in the bath. At the expiration of this period the bath should be quiet and the oil is turned back on under 40 lb. of steam pressure. This continues for 10 min. and by this time the melter normally receives a report on carbon and manganese for samples taken from the bath just before the silicomanganese was added. If results are satisfactory final samples are taken from the slag and bath, and 2000 lb. of 80% ferromanganese is added to the heat. Steam pressure is increased to 60 lb., and the manganese is completely melted during the 15-min. period required for laboratory analysis of tapping tests. As soon as chemical results are received final adjustment to manganese content is made and this seldom requires more than 100 lb. of 80% ferromanganese. As the heat is tapped, aluminum, ferrotitanium, and ferrosilicon are added to the ladle. It was stated that with the old method of using silicon pig iron for blocking, melters finished within the specified manganese range on only half of the heats tapped, but with silicomanganese, more than 90% met the manganese specifications. In addition to describing this finishing practice, the paper stressed the importance of specifying steam pressure to be used for fuel throughout the melting period.

Other interesting figures were given on the use of silicomanganese as a furnace block. It has been found that one point of silicon (0.01%) added for each 1% of FeO in the slag will hold carbon constant for 1 to 1½ min. without danger of phosphorus reversion. Three times this amount of silicon has been used successfully without phosphorus reversion when burned lime was added before the bath was blocked. Use of silicon alloys in this manner enables them to be substituted for aluminum blocks which can be used only sparingly, if at all, under current restrictions on the metal.

Scabs on Ingot Butts

T. J. WOODS presented a paper concerned with the formation of scabs during pouring; it had special interest because it opposed several prevailing opinions on this subject. Data were primarily concerned with semi-killed ingots 24x54 in. in cross section and 82 in. high. These are rolled to slabs for plates, and freedom from scabs is an important consideration.

Several molds were followed throughout their service and some were coated with pitch or tar before each pour while the balance were not coated. Although ingots produced from bare molds had more scabs before they were charged into soaking pits, there was little difference in the amounts of scabs present on the product from coated and bare molds after ingots had been heated and rolled to slabs. Thus it was concluded that those scabs which are caused by omitting mold coatings are almost entirely eliminated by scaling during soaking.

Nevertheless, scabs persisted on the finished product even when heats were cleanly poured and it was noted that these usually occurred in clusters, and on product from the bottom end of the ingot. There was no regularity in size or shape of defects, and it was sometimes possible to fit separate scabs together like pieces of a jigsaw puzzle. This indicated that these defects had originally existed as one piece, and further investigation led to the conclusion that they arise from a shell formed at the bottom of the ingot during initial stages of pouring. The pouring stream strikes the mold stool and the splashes rebound against the mold wall, solidify, and form a veneer or shell. As the pool of metal in the mold increases, splashing becomes progressively less so that the "shell" is confined to the extreme mold or ingot bottom. This shell may be 14 to 20 in. high on the mold walls before 3 in. of the ingot has been poured. Therefore the extreme ends and corners of the shell form scabs because they completely solidify before molten metal can rise to melt or weld them into the ingot proper.

(Continued on page 944)

Beryllium—

Facts about the metal, rather than *Fancies*

EDITOR'S INTRODUCTION — During the early days of the Office of Production Management, the Metals Reserve Co., and the U. S. Treasury's purchase of strategic materials, great pressure was brought to bear on officials in those governmental groups to "get busy and do something about beryllium". Even so accurate a reporting service as *Science Service* was guilty of broadcasting the following:

"Beryllium, two-thirds as heavy as aluminum and several times as strong, may produce greater changes in the next 10 years than aluminum in the last 30. Military and transport planes, airplane engines, other means of transport; machine tools; electrical equipment and dozens of other fields, on many of which the metal has not yet made even the slightest impression, will feel the effects of the feathery light metal whose remarkable properties include, when properly alloyed, a strength higher than that of steel."

Testimony by the President of the Beryllium Corp. of Pennsylvania before the Temporary National Economic Committee (the "Anti-Monopoly Investigation of 1939") concerned the difficulty he had had prior to 1934 in securing licenses to use patents on the manufacture and use of beryllium and its alloys issued by the U. S. Patent Office to the German electrical concern of Siemens and Halske.

This testimony touched off a continuous stream of articles in the daily newspapers and the popular magazines. The result was to form a picture in the average American's mind that the production of beryllium, the lightest metal, and its light alloys, had been feloniously restricted to the great detriment of the American aircraft industries, and were it not for this, the new metal would have long since replaced aluminum and magnesium as a super-light, super-strong metal for super-speedy aircraft. These assertions are so far from the truth that the statement of facts recently issued by the War Metallurgy Committee is in order. First, however, a brief note about the American developments may be timely:

Charles F. Brush, Cleveland pioneer in the electric lighting industry, inventor of the arc light, and founder of the Linde Air Products Co., became interested in the metal in 1921 and employed C. Baldwin Sawyer to conduct laboratory work. From this grew Brush Beryllium Co., with reduction plant in Lorain, Ohio, producing mostly a master alloy containing 4% Be, 96% Cu. Price was $30 per lb. of contained beryllium until 1937; at present it is $17 — which still sounds expensive.

Hugh S. Cooper, who had had a patent on it for several years, and Maurice D. Sarbey also commenced working on beryllium in Cleveland about 1923. They were employed by one of the subsidiaries of Union Carbide & Carbon Corp. It was about the same time the Germans began exploring its possibilities, and out of the German efforts came the patents Siemens & Halske hold. Carbide & Carbon later offered its patents for sale, and from them stemmed the Beryllium Corp. of Pennsylvania in Reading. The fundamental patents on the reduction process and the copper alloys are old and have expired, so the principal efforts now are to devise ways and means of producing the metal more cheaply and to widen its field of usefulness. As shown in the following report, the principal obstacle is the scarcity of ore.

Digest of a Report Dated April 1943 to the War Production Board by the Advisory Committee on Metals and Minerals of the National Academy of Sciences:

1. Beryllium is a metallic element used chiefly in the production of heat treatable, strong copper base alloys for electrical contacts, clips, small springs, and similar metallic parts. It is

also used in fluorescent lamps, X-ray tubes and ceramics. It may possibly be used as an alloy for magnesium and aluminum.

2. The potential use of beryllium exceeds the present supply, thus indicating *(a)* the immediate need for more sources of beryllium ore — particularly in this country — and *(b)* the limiting of new uses for beryllium and the study of possible substitutions until such a time as more beryllium ore is available.

3. American consumption of beryllium ore in 1941 was about 2500 tons, mostly imported from Brazil and Argentina. Our present stock of ore in private companies now totals about that figure, and can last at present consumption rates until summer. About 6000 total tons of ore are desired for 1943, and may reasonably be expected.

4. More than 90% of the demand for beryllium metal is for the beryllium-copper alloys. Currently, the American production of beryllium-copper master alloy containing around 4% beryllium is at the rate of about 3,000,000 lb. per annum. The demand appears to be some 40% above the supply. However, expansion of facilities for its production is under way, sufficient to produce around 10,000,000 lb. annually. No corresponding expansion is projected for other beryllium products.

Well Developed Hexagonal Prisms of Bluish-Green Beryl in a Piece of Coarse Crystalline Granite (Pegmatite). Beryl is intermediate in hardness between steel and glass, is frequently semi-transparent. Colors vary and may assume the color of the enclosing rock, being at times either brown or white

The Uses of Beryllium

The principal use so far developed for the metal is in the production of strong, heat treated copper base alloys in which the beryllium content varies from about 0.3 to 2.5%.

The second most important use of beryllium, though much smaller, is in the form of oxide or other non-metallic products in the fluorescent lamp, X-ray, cathode ray, and television industries. Certain beryllium salts have the quality, in common with several other materials, of transforming short-wave radiation and cathode rays to visible radiation. Such materials are commonly known as phosphors, and the beryllium salts are the most important ones now in use.

The third largest use for beryllium is for ceramics, including refractories. Beryllium metal is also used in small quantities.

The present source of beryllium is the mineral beryl, found in pegmatites, in which, commercially, the beryllium oxide content is about 10 to 12%, and the metallic beryllium content is about 4 to 5%.

Beryllium Ores

There are some 30 beryllium minerals but most of them are rare and have never been seriously considered as commercial sources.

Typical chemical analyses of the more important beryllium minerals follow:

	Chemical Composition			
Mineral	BeO	Al_2O_3	SiO_2	Others
Beryl	14.0	19.0	67	
Chrysoberyl	19.8	80.2		
Phenacite	45.55		54.45	
Helvite	13.6		32.5	51 MnO, 5.8 S
Idocrase	9.2	9.70	34.25	CaO, MnO, ZnO

The present consumption of beryl ore is at the rate of about 7 tons a day and may reach 20 tons per day later in 1943, if adequate ore supplies are obtainable. It is now estimated that at least 8000 tons will be needed in 1944.

The wider utilization of beryllium for the war effort depends primarily upon the quantity of beryllium ore that can be obtained. Scheduled requirements of beryl ore represent an opinion as to available supplies rather than quantities that would be used if more could be obtained.

Most beryllium ore has been obtained as a by-product of mica, lithium, and feldspar mining.

Large crystals of beryl are sometimes found by prospectors, but more often uncovered by feldspar mining. In such mines, a ratio of recovered beryl of one-half ton per 100 tons of rock moved is common. Practically no mining operations have been started primarily because of the presence of beryl, and this remains an important possibility; such mines would have to contain beryl crystals large enough for hand sorting, as concentration methods for small crystals still are unknown.

What is needed is the discovery of one or more veritable "mountains" of beryllium ore. A concentrated search for new and better deposits is clearly indicated.

Generally, beryllium minerals tend to occur in so-called contact zones, by which term geologists mean the regions where the nature of the rocks abruptly changes. Principal source of beryl, for instance, is in pegmatite dikes, regions where liquid rock magma or lava has entered extensive cracks in the earth's solid crust, and there cooled very slowly to a coarsely crystalline granite.

World's production, as estimated by Allan F. Mathews of the U. S. Bureau of Mines, amounted to about 450 tons annually in 1935, 1936 and 1937, and about 1000 tons in 1938 and in 1939. Argentina and Brazil produced 2300 tons in 1940 and 4000 tons in 1941 (other countries not reporting). American production of beryl ore has ranged from less than 100 to somewhat more than 150 tons annually, mostly from Colorado and South Dakota.

Canada has several known deposits, one locality producing 177 tons of beryl in 1939. India has possibilities for increasing its operations, and important deposits have been reported in Belgian Congo and in Mexico. The real sources of ore are in South America. Brazil has two rather large deposits inland from the southeastern Atlantic shoreline. Beryllium ore production is affected by the seasonal factor of heavy tropical rains during the period from December through April, when ore is not transported to ports. In Argentina, commercial beryl ore occurs in the mountainous regions which protrude from the plains about midway between Buenos Aires and the Andes mountains. No imports of beryllium in any form have been reported in the United States from Argentina since January 1942, but some shipments are now scheduled.

Stocks in This Country

A canvass of principal consumers recently indicated that stocks of beryl in private hands amount to about 2500 tons, or approximately equivalent to last year's demand (1942).

A 3000-ton stockpile has been authorized by the War Production Board, but only small deliveries have been made. However, the Metals Reserve Co. has a general underwriting agreement with Brazil and recently has placed orders or bids on shipments from several countries.

Recommendations About Ore Supplies

1. Granting a favorable foreign mining and shipping situation, beryl supplies from known sources may aggregate 6000 tons in 1943, but are likely to fall short of an estimated manufacturing capacity (demand) of 7200 tons.

2. Any large scale expansion of the uses of beryllium — in excess of the yield from about 10,000 tons of 10% ore a year — rests upon the discovery and concentration of large low-grade ore or on new discoveries of higher grade ore.

3. Every effort should be made to increase production from western hemisphere mines.

4. If reports of investigators in South America are favorable, steps should be taken to increase production there to the economic limit.

5. Unless new favorable developments change the overall picture, not more than 6000 tons of ore should be scheduled for consumption in 1943, and any ore over and above current requirements should be stored until a stockpile of 10,000 tons is created or until large new domestic sources of production are tapped.

Production of Master Alloy

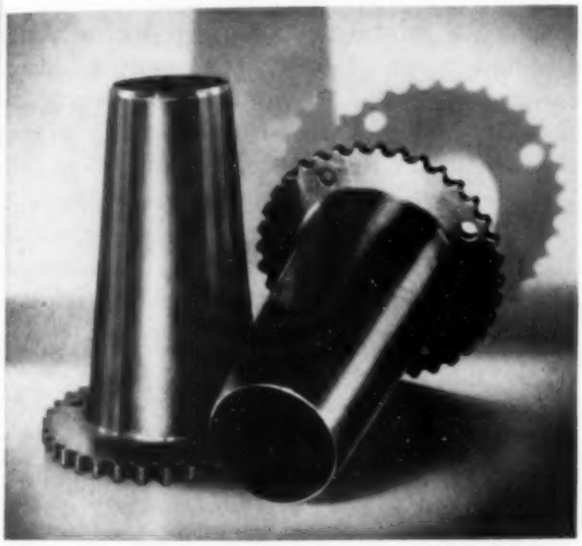
The chief use of beryllium is for beryllium-copper alloy to obtain a strong, heat treated metal for electrical contacts, clips, small springs, diaphragms. For the production of these copper base alloys containing beryllium, a so-called master alloy containing about 4 to 4.5% beryllium is first produced. The final copper base alloy has a beryllium content varying from about 0.3 to 2.5%. [*Editor's addition* — The master alloy is produced by Brush Beryllium Co., the leading interest, directly in a simple arc furnace from a charge of carbon, beryllium oxide and copper. The basic idea was patented by Lebeau in 1897 but was abandoned by the Germans. Precautions required to make the process commercial were discovered by American research, operating quite independent of the German industry, and are outlined in U. S. Patent 2,176,906.]

Beryllium-Copper Alloys

Beryllium-copper is heat treatable to produce the strongest copper base alloy. Extensive studies have been carried out in various laboratories in endeavors to broaden the use of beryllium-copper alloys and to take advantage of their valuable properties of high fatigue strength, elastic limit

and hardness, relatively high tensile strength and electrical conductivity, excellent corrosion resistance, good wear resistance, good resistance to galling against steel, good resistance to room temperature creep (elastic drift), and various fabrication advantages associated with heat treatment or precipitation hardening. Such studies have now borne fruit to such an extent that the demand threatens to exceed the supply. Both copper and tin are conserved by the use of beryllium-copper alloys when they replace bronzes.

There can be no doubt as to the relative superiority of this alloy for many important applications in both the peacetime and the wartime economy. At the present time beryllium-copper is being used in parts of aircraft, ships, tanks, guns, shells, instruments, engines, motors,



Hub Cones for Adjustable Pitch Propeller, Made of Beryllium Copper (Courtesy American Brass Co.)

radio, telephones, telegraph, tools, and electrical control equipment for machinery and fire protection. Where small parts are involved, design factors often explain the use of this alloy. Thus, in many aircraft instruments, its properties warrant the use of a smaller part than would be necessary with other materials.

Virtually 100% is now going to vital components of direct and indirect military end-products. Accordingly, if supply is insufficient, substitute materials will have to be found. In general, beryllium-copper has replaced phosphor bronze, aluminum bronze, and alloy steel, and these materials provide the most likely substitutes. Alloys containing less beryllium than the conventional 2% variety will, no doubt, suffice for many uses. Recent work on low temperature heat treatment of cold-worked brass and bronze has already resulted in the replacement of some beryllium-copper springs.

Nickel-Beryllium Alloys

Physical properties of age-hardening alloys of nickel are good, but are obtainable in other alloys of nickel at lower cost.

Beryllium Metal

Beryllium metal is used to make vacuum tight windows for X-ray tubes. The metal is first made in a vacuum melting equipment and cast into small ingots. The metal can then be hot rolled — the rolled pieces having a very slight plasticity and bendability when cold. They can be mounted as windows in X-ray tubes and have the advantage of transmitting soft X-rays up to 20 times as well as the next material. [*Editor's addition* — C. Baldwin Sawyer, the American authority, writing in *Metals and Alloys* for October 1940 said: "If a revolution can be effected in industry through the use of beryllium, it would probably come by making this 'light', brittle material ductile. The same may be said of the element silicon, which is almost as 'light' as beryllium or magnesium and vastly more abundant than either, though too brittle for direct use. The commercial production of ductile beryllium seems still far removed from the present, and there is therefore no purpose in stressing its light weight."]

Magnesium-Beryllium Alloys

It has been reported that a small amount of beryllium is helpful in connection with the manufacture of magnesium base castings. Beryllium is almost insoluble in molten magnesium at all temperatures, and there are no magnesium base alloys containing any substantial percentages of beryllium.

Aluminum-Beryllium Alloys

A great deal of work has been done looking toward the development of a suitable aluminum-beryllium alloy. Tests on certain alloys, made experimentally, show that the hot strength is considerably above that of other aluminum alloys. The thermal conductivity is also of a high order, and the thermal expansion is low. These properties seem favorable for aircraft pistons and certain other engine parts. After much experimental work there has been some progress in producing workable ingots of approximately 35% beryllium weighing 10 or 15 lb. Even from these small ingots small instrument parts and various specialties requiring low density, stiffness, and good machinability could be *(Continued on page 942)*

Critical Points

By the Editor

To Marysville, north of Detroit, to attend the formal opening of one of the new magnesium plants, this one built in nine months by Austin Co. for Uncle Sam's Defense Plant Corp. and operated by Dow Magnesium Corp. Chief raw materials are magnesium chloride (purified from brines pumped out of the earth), electric power, and "know how", the last supplied by a continuous developmental program since 1916 standing at about $3 million on Dow Chemical Co.'s books — and let it be said, the one thing that could not have been created in a few months no matter how dire the national emergency. Power is brought in on high tension lines, transformed to low voltage direct current in mysterious looking tanks said to contain electronic tubes (but why should a vacuum tube be more "mysterious" than a rotary converter or any other electrical device?) From the substations to the cells, in long buildings adjoining, the current is carried in silver busbars, the metal being loaned from the Treasury's hoard. Much to-do was made over the supposed value of $18½ million for the 900 tons of it, based on the political valuation of 71.1¢ per troy ounce, for methinks it would be illogical to value it even at 45¢, the open market price for silver, but rather it should be regarded as of worth no more in this service than the copper it replaces....Surprised at the complex metal construction of partitions, coiled anodes and their connections within the electrolytic cell itself — a gargantuan bath tub made of 2½-in. steel plate — possibly unduly surprised, for on second thought recalled that the reduced metal is so light that it floats on the electrolyte, yet the carbon electrodes bringing current in must pass through this metallic layer which would undoubtedly and effectively short-circuit the whole unit unless the composition and temperature of the electrolyte be accurately controlled for high conductivity, the anode-to-cathode gap be small and uniform, and the supernatant metal led away as fast as it collects....Cell feed is somewhat different from that used in the early days of the Dow magnesium process; the granular chloride now contains one molecule of water of crystallization.

New plant for making magnesium

Gases drawn off from under the cell's roof are a mixture of chlorine, hydrochloric acid and steam, of no present economic value; they are converted to dilute HCl in an adjoining plant and neutralized in the "hard" waters of Lake Huron, flowing down the river nearby. ....Everywhere is evidence of desire to save critical materials. Roof trusses of wood rather than steel; whole building frames of reinforced concrete; walls and partitions of brick; storage silos of cement blocks; acid handling equipment of ceramics and wood; conductors of silver — yet nowhere, the Austin Co.'s engineers aver, is there any harm to correct design or functioning.

To General Motors Research Laboratory, and spent a stimulating morning with John Almen and his staff, who are now translating their accumulated experience with life tests on automotive parts to the correction of fatigue failures in ordnance. Three or four concepts are fundamental to the work: First is that the chemical analysis of a steel, if it is a clean, sound steel, has relatively little to do with fatigue failures in service. Even in precise laboratory testing, the "endurance limit" works out to be close to 50% of the ultimate tensile strength, and since steels may vary from 60,000 ultimate to 250,000, this means that composition and heat treatment have an influence whose magnitude is theoretically at most on the order of four to one. Even this difference vanishes in steels heat treated to the same hardness; irrespec-

Fatigue no respecter of alloy steels

tive of chemical composition they then have substantially the same strength in tension and the same laboratory endurance limit. Yet ALMEN showed some full-sized tests on a simple shape where nothing but easing the fillet radius on an end-boss increased the service life seven or eight times! Tests like this prove that design has a far greater effect on satisfactory *performance* than nature and condition of the metal....Still there are those who are worrying about the lack of fatigue tests on the new NE steels! Even if they should forget the above considerations they should remember that nobody knows how to use the laboratory endurance limit in engineering design.... Thinking further along this line of substitute steels, recollected that some years ago the Cadillac transmission was redesigned; expensive high alloy "Krupp" gears were replaced by simple low alloy S.A.E. steels and the weight reduced 50%, yet the minimum test life under maximum load increased 4½ times. When the shape of the gear teeth was improved for correct application of load, the bearings changed and supports strengthened to minimize the elastic misalignments, the damaging repetitive stresses were so lowered in intensity that almost any steel would endure!

A SECOND fundamental concept is that fatigue failures are *always* due to tension stresses. Compression fatigue is impossible — or, put in another way, compression loads may induce damaging tension stresses in conjugate direction, but it is the tension stress that causes the crack. Add to this concept the fact that most fatigue failures start at the surface and you arrive at the corollary that the way to improve further the fatigue resistance of a well-designed machine part is to lock up some internal compressive stresses within the surface to neutralize at least a part of the tensional service loads....There are several ways of doing this — most simply by proper quenching. For example, a hollow cylinder-head — a heat treated aluminum alloy casting — failed by fatigue, and the crack started from the inside of a water passage. The cure was to quench from the solution heat by a jet through the internal water passages; the surfaces first chilled have compressive stresses induced in them....A second way is by nitriding, which builds up chemical compounds of larger volume than the original iron, and so sets up a surface layer of alloy in compression. (Carburizing also increases the volume, but unfortunately the temperature is so much higher that the core creeps under the load and relieves most of the stress induced in the case by the added amount of carbide; even so, the changes of volume on martensitization give a somewhat compressed case and tensed core.)....The third way is by far the most potent — peening, shotblasting, burnishing, or otherwise cold working the metal to a depth proportional to the size of the piece. This brings us to a surprising situation where a propeller shaft, peened by shotblasting, may have a surface as rough and sharp as emery paper; it would appear to be infested with stress raisers or notch effects, yet the "cold working" treatment raises the life at working loads tenfold!

Compressed surfaces improve endurance

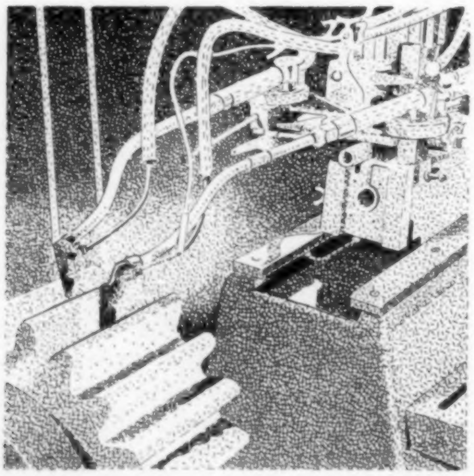
TO HARRISON, near Newark, and was welcomed at the Hyatt Bearings plant by TOM COUNIHAN and other metallurgists in his department. Found that "standard" roller bearings (in contradistinction to aircraft bearings) are made of carburizing steels, but that most of them have been changed from the S.A.E.4620 to an analysis that conserves nickel, the so-called "Roller Bearing Engineer's Committee Steel", containing 1% nickel, ½% chromium and ¼% molybdenum, popularly called RBEC-4620. Adoption of this steel was not difficult, as one important roller bearing maker had determined, in many years' study, that the 2% nickel in S.A.E.4615 could be cut in half without detriment to manufacturing, test, or service performance. At Hyatt the finish-machined races and rollers are gas carburized and oil quenched direct from the retort, then requenched from 1525° F., washed and tempered in continuous units — requenched not so much to refine the grain as to improve the uniformity, point to point, and piece to piece. (Moderate to large sized races are quenched in fixtures.) Final operation is grinding.....Roller bearings for aircraft are mostly of 52100 (1% C, 1¼% Cr), possibly because designers have been impressed with the good performance of ball bearings made of

Low nickel steel for roller bearings

this steel and are loath to make any changes. To save weight the races are comparatively thin — more like a hoop. To avoid distortion they are time-quenched on a fixture; the hot ring contracts as it cools, grips the fixture and "sets" itself while still in the ductile austenitic stage. As the change to hard martensite occurs with further cooling, the hoop expands slightly and frees itself. The operation is critical; oil temperature must be constant; pressure is maintained steady by a gravity tank at each machine; time control is automatic so the ring comes out hot and smoking at 275° F., to cool in air. Each ring is tested for run out — if out-of-round beyond limits it is brought to dimension during the tempering operation..... COUNIHAN emphasized the importance of correct inspection in all these operations in mass production. Seemingly the more "automatic" the machinery becomes, the more sure you must be that unexpected maladjustments do not produce quantities of off-limit material before the first bad one is discovered. A critical operation is grinding — how insure that no piece is abused? Completed aircraft rings are 100% magnafluxed, which spots any grinding cracks. But how about less damaging abuse that merely produces a superficial soft spot? Tempered spots may be shown by a short etch in 5% nital, followed by a dilute hydrochloric acid dip to brighten the etched surface. (This acid attack is so very slight that final buffing or burnishing gives an acceptable surface.)

Thin races held to close dimensions

Inspection in mass production



DEVOTED too short a day to the copper refineries bordering Raritan Bay, location of such unconventional operations as the casting of pure silver slabs for busbars, 300 tons of gilding metal (a 10% zinc brass) from a single copper refining furnace, and continuous casting of 3-in. billets of phosphor copper — and in all that day could but give cursory view to operations at the Barber plant of American Smelting and Refining Co. Fortunate, however, in being guided about by ALBERT PHILLIPS, superintendent of the research department which has tackled all manner of problems in the refining of the principal metals copper, lead and zinc, and the usual byproducts gold, silver, antimony, bismuth, cadmium and indium. New methods are developed in test tube or scorifier, then transferred to dwarf commercial equipment specially assembled, then to a pilot plant which forms the basis of engineering design. The inevitable Censor deletes mention of two extremes in this gamut now under development.....Fascinating is the story of the enormous amount of work locked up in the complete set of standards, metals of exceeding purity and alloys made thereof, all forming the basis whereby new products and methods can be appraised. For example, the gravimetric estimation of traces of bismuth in lead may take 12 hr., and a 150-ton kettleful of metal may be waiting the result. With the help of these standards, colorimetric methods have just been developed in the Barber laboratory by CLARENCE ZISCHKAU, whereby a more accurate determination is made in 15 min., briefly as follows: A weighed sample is dissolved, an organic reagent added and diluted to standard volume. The colorimeter contains an incandescent lamp whose light is passed through a color filter, the solution, and then to a selenium cell. A "blank" solution calibrates current from the cell, and is then replaced by the "unknown solution". The galvanometer reading is taken and the bismuth content read from a tabulation. There are no known interferences. Very slick! — much smoother than the fast colorimetric methods used by steel works chemists for molybdenum and titanium; the latter depend on visual comparisons with standard colors, and these are not too precise or permanent. ....As can be imagined, much work of a novel

Chemical analysis by colorimeter

Brisk sales of a new lead alloy

nature has resulted from the war's dislocations. For example, the subsidiary Federated Metals Division, interested in scrap reclamation, is now getting quantities of wrought aluminum scrap averaging 0.5% magnesium, and the demand is for casting ingot containing less than 0.10%. So a process was worked out for removing the magnesium. While the light metal (aluminum) section of the company is busy removing magnesium, the bearing metal section (lead) is adding it to form a high-strength lead alloy, as follows: Bell Laboratories had long since discovered the excellent qualities of calcium as a hardener for lead cable sheath, but PHILLIPS was bothered by the difficulty of putting calcium into the lead and keeping it there. He found that a little magnesium stabilized the calcium, and a little tin stabilized the magnesium — whereupon he discovered that he had a totally new alloy. The age-hardening particles are probably CaMgSn complexes; the new alloy is six or seven times as creep resistant as "chemical" lead, and consequently lead pipe and lead sheet may safely be made of one third the old weight, or even less. Since lead is just now the only common metal that is not sharply restricted for war production uses, it results that a nice business is available for sheathing, and for "Tubeloy" pipe for water services and for handling many commercial fluids at pressures up to 125 psi.

Bell Telephone Laboratories deep in war work

TO THE giant research laboratory newly built by Bell Telephone within a spacious estate atop the New Jersey hills, where metallurgical equipment now fills a floor in one of the wings. Metallurgical studies in the old New York building during years past were concentrated on the properties of the conventional metals used in telephone equipment, and improved or usable substitutes therefor, and so a mass of information was accumulated of immediate value in saving the critical war metals. For example, a five-year study of solders determined the low limit of tin (32% alloy) that has wide enough "mushy range" to make a wiped joint; it also discovered that the bulky plumber's joint was frequently unsound in deep-seated regions where mother liquor drained away from the solidified particles, and therefore that a much tighter, better, cheaper union could be made if most of the solder were wiped away, leaving only a small fillet at the joint. EARL SCHUMACHER, who directs the metallurgical research, told of intensive studies into the electrical — or should I say electronic? — properties of several metals, some rare and precious, others common but no less precious, going into all manner of transmission and detection devices. For the present any details are ultra-confidential, but as far as the Editor is concerned, the subject of electronics is at all times a closed book!....In many instances the excellent laboratory equipment is operating as a production unit for items necessary to munitions but not yet commercial, such as wires that are not much bigger than a spider's web, metal tape that is almost as thin and perfectly flat, numerous composite metals (overlays, inlays, and edgelays), metallic microcosms of mysterious surface contours and properties.....When faced with the necessity of designing a central laboratory, Bell Laboratories, with its usual prescience, built a small section of the building — a veritable laboratory test cell — and studied to make it more adaptable for ready apportionment of space by standardized steel partitions, and by this means solved the problems of ventilation, heating, lighting, and the ready availability in every 12-ft. bay of the 15 services — water, gases, electricity. One penalty of such leadership will be to entertain and instruct a long procession of those who want to build or enlarge their own research quarters.

OBSERVED the following in many cities in the want ads:

Wanted Immediately
Men and Women Trainee Welders
No Experience Necessary
Apply U. S. Shipyards

and opined that there may be some connection between them and the news item from Portland on Jan. 16: "Liberty Tanker S.S. Schenectady Breaks in Two and Sinks at Dock After Completing Trial Run". (Perhaps also to the disappearance, without trace, of the then largest all-welded ship, the 260-ft. ship Joseph Medill, on her maiden voyage across the Atlantic early in the winter of 1935.)

By Robert B. Schenck
Chief Metallurgist
Buick Motor Division
General Motors Corp.

Steel Cartridge Cases From Extruded Cups

A PAPER on steel cartridges was prepared by the present writer for the January 1943 meeting of the Society of Automotive Engineers, but was suppressed by the Censor. At that meeting Lt. Col. Harold R. Turner, chairman of the Cartridge Case Industry Committee, discussed the general situation, as noted briefly in *Metal Progress* in March, and elaborated considerably on his earlier talk before the Chicago Chapter ⊕. In the Chicago address (see *Metal Progress,* page 51, January 1943) Lt. Col. Turner mentioned that slugs of steel were being converted into a shallow cup by hot forging methods, but that this operation was confined to two organizations where ample equipment and experience had been accumulated as a result of specialized peacetime operations. One of these is Buick Motor Division of General Motors Corp. The process, which will be described in this article, and which has been made available to the U.S. Government for use by other manufacturers without license, differs from other processes principally in its early stages, for cartridge cases, either of steel or brass, ordinarily start as a round disk, and are formed by a series of cold cupping operations.

Before entering into a discussion of the metallurgical and production aspects of the Buick process, a brief outline of its history may be of interest. The project originated with a letter from the Navy Department in July 1941 asking for ideas on a steel cartridge case. At that time only bare dimensions were available and we were in possession of no technical information as to metallurgical and physical requirements. It appeared that military and naval authorities had very little data on which to base specifications. The Buick management immediately provided funds for carrying on original work, which was done on an extruding die about one-third the size required for a 5-in. naval case. Preliminary efforts were mainly concerned with meeting dimensional specifications rather than physical properties.

The first extruding die worked satisfactorily, so experimental redraw and heading dies were made and the first case was produced. The Buick management was favorably impressed with the sample case and submitted it to naval authorities who asked that development continue. Work was started on tools to carry a 3-in. steel cartridge case through the redraw operations. (This size was adopted because experimental work could be carried on faster with this smaller piece than with the 5-in. size.)

While this work was in progress other meetings were arranged with both Navy and Army Ordnance personnel. In November 1941 the Army requested Buick to develop the 75-mm. case while the Navy decided to be guided by the Army's findings. This was the beginning of our program on the 75-mm. steel cartridge case.

Mechanical Requirements — The purpose of a cartridge case is to act as a container for the explosive charge, to prevent the escape of gases resulting from the explosion, and to permit more rapid firing than would be possible without fixed ammunition. The wall of the case must be elastic enough to expand under the explosive pressure and make a tight seal against the wall of the gun, particularly at the mouth of the cartridge. Unless it is properly supported by the breech wall, the pressure developed is sufficient to burst the wall of any case, firing pressures of 60,000 psi. being built up in 0.002 sec. A certain amount

of clearance is necessary between the cartridge case and the breech wall to permit ease of loading and ejection under field conditions. The cartridge case must expand, first to take up this clearance, and then continue to expand as the gun's diameter itself increases due to the explosion pressure. The case must have enough elastic recovery to be easily ejected after firing. In contrast to the high physical properties required in the body wall and base of the cartridge case, the mouth must be annealed to insure complete obturation (seal against back fire of propellant).

It is necessary to have a higher yield strength on a steel cartridge case than on brass because of the higher modulus of elasticity of steel. The modulus of brass is 14,000,000 against 30,000,000 psi. for steel. The stress within the elastic range to produce a given amount of strain in brass is therefore approximately one-half that of steel. Other considerations are corrosion of steel and sparking on impact, both of which must be overcome by a suitable protective coating. The steel cases must also be interchangeable with the brass.

Fig. 1 — Tocco Induction Heater for Heating 3⅛ In. Dia. by 1¾-In. Slugs. Yellow gas flame prevents oxidation of the previously ground surface

Metallurgical Requirements — The required physical properties of a steel case can be obtained either by cold working alone, or by quenching and tempering before or after cold working. Cold working alone involves the least number of operations, fewer shop problems, less equipment, and has been found adequate by some 50 manufacturers. On the other hand, heating and quenching after cold working distorts the case; this must be controlled by intricate quenching dies or by additional sizing operations. Quenching followed by cold working eliminates the distortion problem and has been employed successfully on experimental lots. Where cold working alone, or quenching before cold working is employed, a final stress relieving treatment should be used to further improve the physical properties.

In the selection of a material, a low carbon steel was chosen which could be cold worked and stress relieved to the required physical properties without resorting to a spheroidizing treatment prior to cold forming. Among the compositions tried during the development were S.A.E. 1015, 1016 and 1020, A.I.S.I. C-1019, and a higher manganese type containing 0.20% carbon and 1.29% manganese. Experimental lots of C-1019 included coarse grained, fine grained, aluminum killed and silicon killed steels.

The steel finally adopted, and now in production, is an openhearth, high manganese, aluminum killed, fine grained carbon steel in round bar form. Of utmost importance is the physical quality of the raw material. Best mill practice with regard to discard, surface conditioning and macrostructure is essential in producing suitable steel for cartridge cases.

As in all structural applications where stress is involved, the material in a cartridge case must possess a certain combination of strength and ductility for successful performance. In the side wall of the 75-mm. case, except at the mouth, the yield strength must be upwards of 100,000 psi., high enough to prevent a degree of permanent set sufficient to cause difficult ejection. Also, the ductility must be adequate in all sections to prevent rupturing from the explosive pressure. Little tolerance is permissible. If the case is too hard or brittle, it will crack when fired; if too soft the explosion pressure will cause it to stick in the breech chamber.

Manufacturing Operations were devised to use machines and equipment on hand at the Buick plant. A list of the major operations is given on the next page.

We started with a 3-in. blank to form the 75-mm. case, but experiments indicated that by

Fig. 2 — Extruding the Hot Slug Into a Cup Is Done in a Standard Forging Press (Crank Type) With Punch in Upper Head and Pot Die in Lower

starting with a somewhat larger blank, it was possible to fill the dies better in the hot operations. Hence, the blank was increased to 3⅛ in. diameter by 1¾ in. thick, although this meant no essential change in the method. Centerless grinding (operation No. 2) provides a more perfect surface, eliminating defects which would tend to carry through the subsequent operations.

Heating for the hot cupping operation is done in a specially built induction heater shown in Fig. 1, page 913, the piece being brought to temperature in 1.5 min. The machine has two fixtures which may be operated simultaneously, permitting a production rate of 80 pieces per hr. During the brief period of heating, a yellow gas flame is directed onto the steel, enveloping it

Schedule of Principal Operations

1. Cut off	14. 2nd cold redraw	24. Machine base
2. Grind O.D.	15. 3rd cold redraw	25. Face to length
3. Heat	16. Trim end	26. Finish ream & counterbore
4. Extrude	17. 4th cold redraw	27. Inspect and repair
5. Redraw hot	18. Bonderize	28. Stress relieve
6. Size cold	19. Cold head	29. Phosphoric acid pickle
7. Anneal	20. Flame anneal	30. Paint
8. Pickle and rinse	21. 1st taper	31. Bake
9. Coin head	22. 2nd taper	
10. Bonderize	23. Flame anneal	
11. Draw		
12. Trim end		
13. 1st cold redraw		

and preventing scaling. The current kicks off when the piece has been brought to temperature, and it is then transferred to a gas fired muffle furnace where it is held for 7 min. to insure an even temperature throughout.

Extrusion is done in a standard forging press, of the crank type common to many automotive shops, shown in Fig. 2. On this press the upper die member is a punch made of hot die steel, nitrided for improved wearing qualities and rounded at the end to form a smooth radius at

Fig. 3 — Four Successive Drawing Dies in One Large Press; the Force Required to Extend the Case 9 In. Is Divided Into Four Equal Parts

the base of the cup. The lower die is a cavity having the size and shape of the formed cup, and virtually the same diameter as the heated blank. The punch extrudes metal up between punch and die wall, forming a cup about 4 in. high. A standard forging grease or graphite paste is used to lubricate the dies and there is no trouble with sticking, because a stripper on the punch removes the part on the upstroke.

In the early stages of the work only one hot cupping operation was used, but it was later determined that better results could be obtained if a second hot operation is carried out after the piece had cooled somewhat. The second hot press is the same as the first, except for slightly altered tooling which extends the draw 2 in. further, making the cup about 6 in. high.

After the original set-up was worked out, an extra operation was added to control the wall thickness. In this the cup is cold sized in a press, drawing it out only slightly. This is done after the hot, redrawn cup has cooled in air.

The seventh operation in the schedule is annealing to bring the partly drawn case back into the soft condition. Note that this is the only anneal in the entire manufacture, and so the making of a steel case is much more direct than the making of a brass case which requires several intermediate anneals interspersed among the forming operations. A considerable economy in time and expense is so effected. Annealing is done in a short gas-fired furnace, with two-zone control; cases are set on end in rectangular trays, and trays are pushed through the furnace at correct speed.

After annealing, followed by acid pickling and washing to remove scale, the head of the cup is coined in a crank press. This operation sizes it accurately and gives this portion of the case some extra cold work, because in the subsequent cold drawing operations the head does

Fig. 4 — *Cold Heading (Principally Upsetting Rim for Extractor) Is Done in Two Strokes of Press, the Lower Die Being Moved to Second Station Between Impressions*

not receive as much work as the walls. Bonderize treatments serve both to clean the surface thoroughly and to etch it slightly so that minute pockets will retain drawing compound. Further, the thin layer of zinc phosphate deposited in this chemical treatment acts itself as a lubricant.

Hydrogen embrittlement resulting from acid pickling and bonderizing tends to cause breakage during cold drawing. This trouble is eliminated by baking, which drives off absorbed hydrogen.

Perhaps the most interesting step in the entire operation is the series of four cold drawing operations, all carried out on a single 750-ton Clearing double acting press. See Fig. 3. The four punch and die stations are at the corners of a rectangle well within the normal platen area, and are so arranged as to carry approximately an equal load, of somewhere near 150 tons per station. The depth of draw (addition to length of cup during the operation) varies slightly over the four dies, being controlled by the length of the punch. The cartridge case progresses from the left hand die to the right hand die on one side of the press and is then handed through the press opening and placed on the die directly across from the second station, finally moving to the right hand die on that side. Four operators handle the cases, one at each die. Each punch has an integral mechanical stripper which removes the part after drawing.

On this press, the 6-in. cup is drawn to a length of 15 in. and to the approximate internal form and external diameter of the finished case, a total draw of 9 in. with no intermediate anneal. This is a real test of the drawing qualities of the steel, and it is noteworthy that few pieces are torn or split. A special drawing compound was developed, whose base material is machine oil.

Punches used on all the cold drawing and tapering operations are made of hardened high speed steel, chromium plated. Plating improves wear and provides better anti-frictional properties. Drawing dies in the cold operations are generally steel rings with tungsten carbide inserts on the working surfaces.

After the open end is trimmed the case is bonderized a second time and then cold headed

Fig. 5 — Row of Radiant Gas Burners Soften the Mouths of Cases as They Pass Along, Slowly Rotating to Spread Heat Uniformly

in a press equipped with a two-stage indexing die (Fig. 4), the lower die being built so that after the first stroke it can be moved across the press, bringing the second die impression under the punch carrying the case. In these operations the base is flared out so that the flange can be machined, the steel to fill this expanded rim being furnished by the extra thickness formed around the outer edge in the original hot cup.

The next operation — No. 20, flame annealing the mouth before tapering — is quite critical. See Fig. 5. Heat is limited at the mouth end to a depth of about 2 in. to prevent splits during tapering. Temperature is closely controlled. In this operation, cases are mounted on a conveyor and moved between two rows of 2½-in. radiant gas burners, mounted in a furnace horizontally at the proper height to concentrate the heat on the mouths of the cases as they travel through the furnace. The cases are rotated slowly as they move past the burners.

Tapering operations are perhaps the most critical of all steps since, in these two press operations, the cold steel must be made to flow into the desired taper without wrinkling or distortion and without the support of a punch on the inside. The case is simply forced up into a tapered die cavity in two stages, both mounted on the same press. The second stage does have a punch which extends about 3½ in. into the case; this is required not for the overall taper but to support the metal in forming the reduced section at the mouth. Taper on the neck of these 75-mm. cartridges is not nearly so pronounced as that on 0.30-caliber rifle ammunition. In fact it looks too slight to be as much of a problem as it actually turned out to be.

During the tapering operations the mouth end becomes appreciably harder because of the cold working, so it is annealed once more, this time to a length of about 3½ in. from the open end. This softens up the mouth and assures complete obturation in firing, that is, a tight seal for a short distance in the gun barrel to prevent the explosion from blowing back into the breech.

Cases are then inspected and transferred to 5-station automatic lathes which face the head, rough-form the flange, finish-form the flange, and drill the primer hole. Great care must be exercised in reaming and counterboring the primer hole since tolerances are unusually close.

Final stress relieving (operation No. 28) is performed at low temperature in a batch type electric furnace accommodating 316 cases. This heat treatment adds roughly 10,000 psi. to the yield and ultimate strength of the cold drawn walls of the cartridge case.

The coating specified to protect against corrosion and sparking is an unpigmented baked phenolic varnish. Before painting, the cases are given a phosphoric acid pickle which provides a bond and also some additional protection.

Painting and baking operations are fully automatic, the cases being mounted vertically on a conveyor with the open end up. They rest on fixtures and as they pass the spray nozzles they can be spun by a motor-driven rubber belt. One spray nozzle is mounted on a traveling arm which descends into the case and lifts out at a uniform speed while the nozzle directs a spray of varnish over the rotating surface. At the same time, outside nozzles are positioned to coat the base and wall thoroughly and uniformly.

Once coated, the cases are carried slowly between two banks of infra-red lamps, 64 on each side. The conveyor loops twice at the end of the lamp bank so that the cases travel three times through the baking zone, requiring 48 min. in a temperature approximating 360° F. When they emerge at the opposite end from the painting station they pass through an exhaust cooling hood and out to an unloading station where they are thoroughly dry and cool enough to handle.

Inspection of the 75-mm. steel cartridge case starts with receipt of the raw material and ends with the final acceptance tests required by the Ordnance Dept., U. S. Army. This inspection can be divided into three classifications, *(a)* raw material, *(b)* process, and *(c)* final inspection for acceptance.

Raw material inspection includes determination of chemical composition, grain size, inclusion rating, macrostructure and physical condition of the bar stock with respect to mechanical defects.

Process inspection includes numerous dimensional checks, hardness tests and visual examination for defects arising in manufacture.

Inspection for final acceptance by Army Ordnance covers hardness, micro and macro examination, ductility, corrosion and abrasion resistance, and ballistic properties.

One unusual type of inspection tool has been developed for close observation of the interior wall. A cone-shaped piece of steel slightly smaller in diameter than the case is chromium plated to a mirror finish. A wire is attached to the apex of the cone and a small light arranged to illuminate the interior of the case and the bright surface of the cone. The unit is lowered to the base of a case and drawn slowly upward while the inspector watches the mirror surface. The inner surface of the case is reflected in magnified form so that any surface defects are readily observed.

By Stewart M. DePoy
Metallurgist, Delco Products Division
General Motors Corp.

Selection of Toolsteel by Its Hardenability

IN THE PAST toolsteel of the water hardening variety has been specified and selected for its particular job by the Shepherd fracture test.* This method is not useful for deep hardening steels of the oil hardening grade. It occurred to the writer that the Jominy end-quench hardenability test could be adapted to all water and oil hardening steels that require a cooling rate of 10° F. per sec. or more to harden. This latter test may be applied not only to a quality specification, but a layout of general curves of these materials can be used by the designer or toolmaker for selecting the type of material required for a particular tool or tool part.

In order to arrive at these curves many samples of various heats were tested and recorded. Samples were taken from various size bars, ranging from 1⅛-in. round to 3½-in. round, which had been rolled from the various heats. This gives a band curve within which will fall all the steel of the particular specification if it is of satisfactory quality.

Let us investigate the possibilities of these curves. First, it is apparent that they may be used to specify *quality* when purchasing toolsteels. They may be used as an inspection standard for received materials. Second, they may be used by the tool designer to select the type of material he wants for his particular design. However, there are other properties of the toolsteels not shown readily on these curves that the tool designer must know about, such as cracking liability, machinability, tendency toward warpage. Nevertheless, the "hardenability characteristic" curve may be very useful to him.

For specification purposes, one may make up his own curves by simply making multiple tests on different sizes and heats of the particular variety of toolsteel. The heats, of course, must already be of proven high quality. Use the standard Jominy end-quench hardenability test, except that the normalizing of the test bar is omitted. It is also possible to set up a theoretical band or curve by simply plotting the points on the desired curve representing the relationship between cooling rate for a given section and resulting hardness. These points are calculated with the aid of the cooling rate curves for bars shown on page 918 and adapted from page 321 of the S.A.E. Handbook, 1942 Edition. These curves will give the cooling rate expected at any distance from the outside for any round section up to 4 in. The hardness required for that cooling rate may then be plotted on the hardenability sheet. Three to four points are generally sufficient for a characteristic curve to specify a toolsteel, and it may be presented to the supplier for metal to meet the requirements.

When these curves are used by the designer he must first calculate the section required on the tool. He should know at what depth he requires high hardness and what hardness he would like at the core. By reference to the cooling rate curves (page 918) he may find the expected cooling rate at these critical points in the section. Then the characteristic hardenability curves will give him the choice of properties that he requires.

Let us examine the hardenability of some commercial toolsteels. In Fig. 1 of the Data Sheet, page 918-A, we see the curve for water hardening toolsteel of the deep hardening grade. The curve at the lower edge of the band reveals that the steel must harden to Rockwell C-60 at a cooling rate of 250° F. per sec. or more. Examination of the cooling rate curves readily gives the depth of high hardness to expect on any size piece of this variety of toolsteel up to 4 in. in diameter. A material of this variety will not harden in oil to C-60 if it is over ½-in. diameter and even then it will harden less than $\frac{1}{32}$ in. deep. (Note that

*See Addendum on page 918.

point A on cooling rate curve for oil quenching a ½-in. round, representing cooling rate of 250° F. per sec. — the minimum for Rockwell C-60 on this steel — is reached at a point less than ⅛ the distance from surface to center.)

Figure 2 is a shallow water hardening toolsteel. Its properties are almost like the material shown in Fig. 1 except that it will harden shallower in sections up to 4 in. Core hardnesses on large sizes will remain about the same for both materials. This steel obviously should be used where very light sections are required.

Figure 3 is for a material that can be quenched either in oil or water. It will harden to a minimum of Rockwell C-60 at a cooling rate of 100° F. per sec. or more. For this material it is necessary to quench in water on bars 2 in. or more in diameter if high surface hardness is required, since only a thin skin at the surface of a 1-in. round cools at the required rate when oil quenched (point B, on the cooling rate curve).

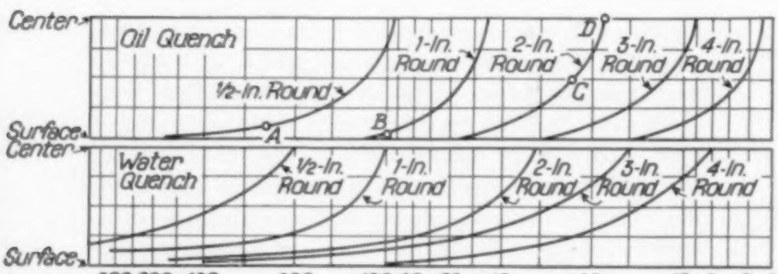
Figure 4 is for a material that is definitely in the oil hardening series. Water quenching on this material is hazardous unless the section is very large. Figure 5 is manganese oil hardening toolsteel. Its hardenability is the highest shown. (Steels that harden to Rockwell C-60 at a cooling rate slower than 18 to 20° F. per sec. are in the air hardening class.) A 2-in. diameter bar of this material of average analysis will harden to Rockwell C-60 at a depth of about ⅝ in., and the core will be at least Rockwell C-56. The derivation of these facts should be obvious. Cooling rate to harden to C-60 is 24° F. per sec., from the upper band of the Jominy hardenability curve. This rate (plotted on the curve for oil cooling in 2-in. round, at point C) is exceeded by all metal from the surface down one-half the way to the center. The cooling rate in oil at the center of a 2-in. round (point D) is 18° F. per sec., and reference to the Jominy curve for the steel under discussion (Diagram 5 in the Data Sheet) shows this rate to give, on average analysis, a hardness of C-56 or 57.

Figure 6 is the curve for silico-manganese shock resisting toolsteel. The wide range shown at the slower cooling rates is due to the wide spread in molybdenum content. Some producers do not use molybdenum in this grade, but in its place use more chromium and vanadium. Vanadium, of course, will lower hardenability if present in quantities of 0.05% or more. If this material is to be used for a specific job, the permissible range of chemistry should be narrowed to suit the job requirements.

The examples shown are only a few of the more generally used toolsteels. However, the method may be applied to any toolsteel requiring a water or oil quench. This method of testing should be excellent for the producer. By using this test he should be able to sort his heats quickly and easily, and apply them to consumers' orders, no matter what method the consumer used for specification.

The method is readily cross-referenced with the Shepherd test by using the cooling rate curves on this page. In general, the Jominy test can be completed in 4 hr. from receipt of the rough sample, while Shepherd tests take 8 hr. or more.

Equipment necessary for the Jominy test is simple and inexpensive. The test itself is described in *Metal Progress* for December 1941, page 911, and on page 317 of the 1942 S.A.E. Handbook. It will be noted that the end-quench diagrams in this article are plotted on the S.A.E. standard sheet which plots distances logarithmically and thus opens up the scale in a useful manner near the quenched end.



Cooling Rates at Various Depths in Round Bars

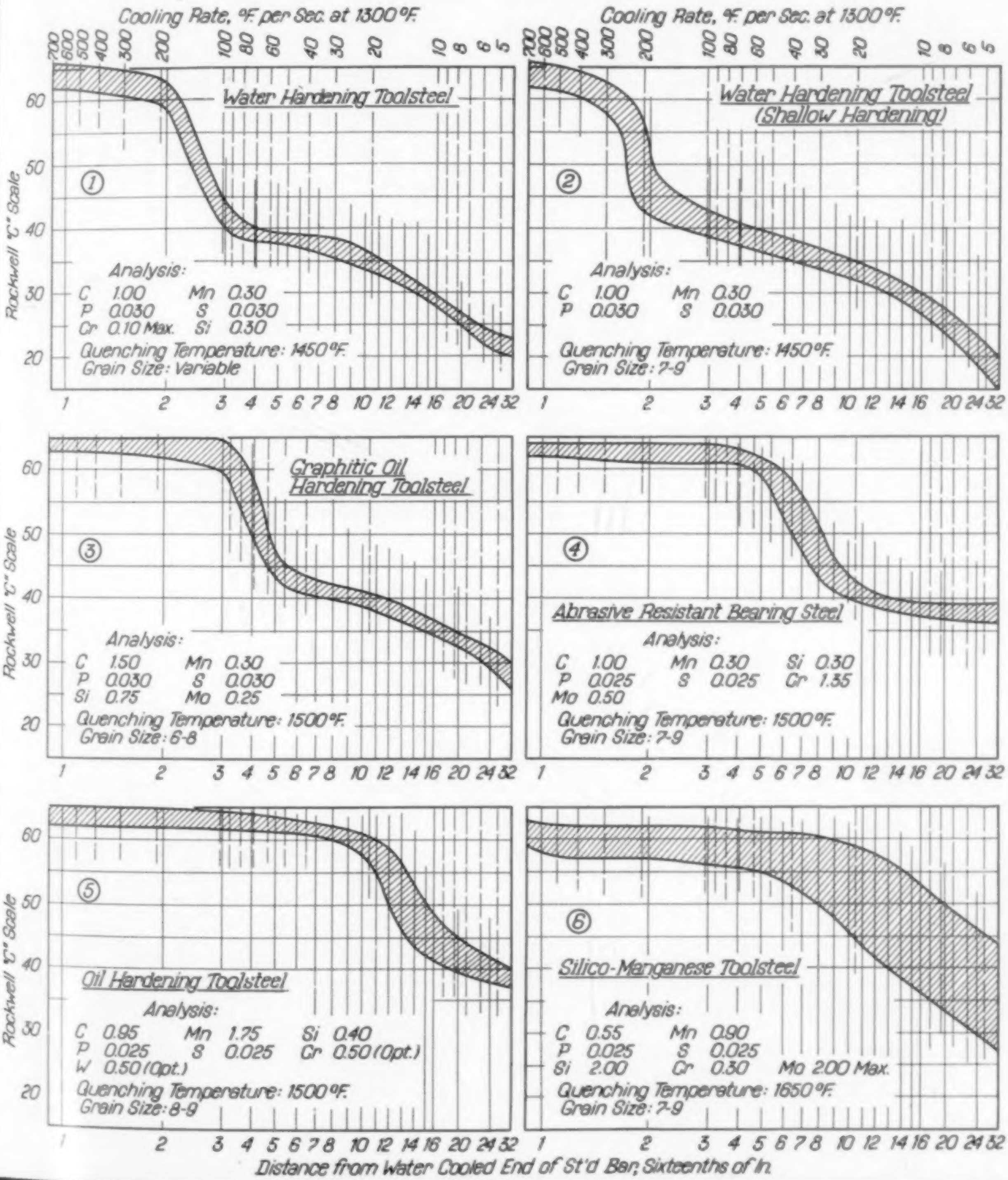
Addendum on Shepherd P-F Test

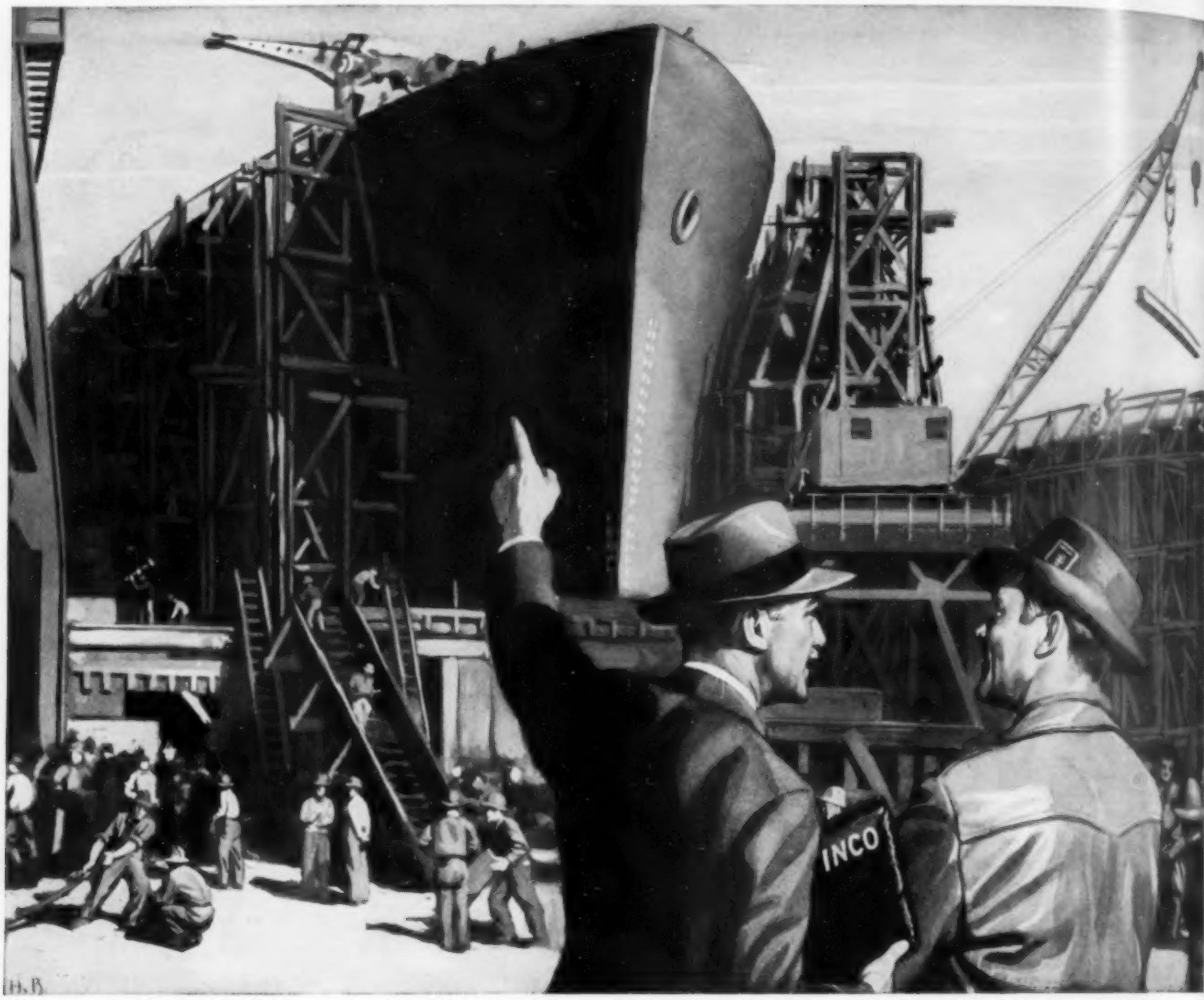
B. F. Shepherd, past president, early studied the so-called "body" of carbon toolsteels, and devised a Penetration-Fracture Test to characterize this esoteric quality. As described in *Transactions* for 1934, page 979, it requires four pieces of the steel, 3 in. long and ¾ in. diameter. All pieces are oil quenched after 40 min. at 1600° F. Samples are then heated individually (heating rate being controlled and uniform) to 1450, 1500, 1550 and 1600° F. respectively, remaining 30 min. at heat before quenching in a vertical cage flushed with 10% brine solution at 70° F. Hardened samples are notched mid-length and broken with a hammer. One end is smoothed to "0" abrasive, etched 3 min. in 50-50 HCl in water at 180° F., and hardness penetration measured to nearest $\frac{1}{64}$ in. The fracture grain size on the rough end is next compared with standards (photographed stereoscopically in *Metal Progress* Data Sheet for August 1942). The "P-F Characteristic" of the steel under test then consists of eight numbers — the first four the penetration of hardness in the respective samples in $\frac{1}{64}$ths of an inch, the second four the fracture grain size of the samples quenched from the lowest to highest heats.

Hardenability of Common Toolsteels

Jominy End-Quench Tests by Stewart M. DePoy

Bands locate tests on numerous satisfactory toolsteels, in a variety of sizes all within normal analytical tolerances, made by Jominy's end-quench method as recommended by the Steel Standardization Group (see *Metal Progress*, December 1941, page 911) except that the bars and test pieces were not normalized before testing. Plotting is done on the S.A.E. standard sheet, which plots distances logarithmically from the water-cooled end, thus opening up the scale usefully for the shallow hardening steels.





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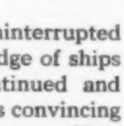

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Ship Plate, Cracked Weldings, and Internal Stresses

However, the reader is urged to keep the correct perspective; to bear in mind that over a period of months some 36,000 tons of steel plate from one converted strip mill were suspect, yet the American steel industry is shipping more plate than that *every day*, all of it acceptable to the purchasers; also to remember that the S.S. Schenectady is one merchant ship out of 746 of the Victory Fleet delivered prior to the turn of the year, and of the 1450 more to be launched during 1943. In studying the few failures, don't overlook the many successes.

Two weeks after the above disclosures, the Steel Industry Advisory Committee of the War Production Board held a well-attended meeting in which the following paper was presented. It will be recalled that the Irvin Works is a continuous sheet-strip mill, converted to the manufacture of plate. It gets slabs from other plants where openhearth furnaces and blooming mills are located. The published testimony seems to infer that the trouble complained of by the Truman Committee arose with "orphan" slabs (for instance, a slab that might carelessly have been marked 26670 when there was no such heat on the books, the most likely being 26870). Regulations were that such slabs or plate therefrom should be withheld from shipment until check analysis could be made; in haste this rule was sometimes violated. There is no suggestion that off-analysis *heats* were rolled into plate.

ON MARCH 23 the Special Committee of the U. S. Senate Investigating the National Defense Program (known popularly as the Truman Committee) heard testimony indicating that a few plates produced at the Irvin Works of Carnegie-Illinois Steel Corp. had been delivered to governmental agencies with incorrect certificates as to chemical composition and physical properties. At about the same time some information became generally current that a 3-months old tanker, the S.S. Schenectady, had broken in two on Jan. 16 when docked at Portland, Ore. Many newspaper writers immediately assumed that the two events were cause and effect.

Since the details have not yet appeared in the public prints, either because of official or voluntary censorship, it is timely to assemble some documents, official and engineering, concerning various phases of this distressing and complicated situation, even though the discussion of a serious accident, a sub-standard metal, or a lapse in stress-relieving technique, tends to magnify its incidence. Yet such information is necessary so that similar circumstances may be avoided elsewhere. (Metallurgy, as a matter of fact, is somewhat like surgery — if everything were always just right, there would be no need for this knowledge.)

Steel Plate for Shipbuilding

By R. E. Zimmerman
Vice-President, U. S. Steel Corp.

THE SITUATION arising from recent investigations, hearings, and consequent publicity regarding the use of steel in welded ships calls for a further pertinent discussion at this time. Insofar as we know, the effective prosecution of the war continues to demand, as heretofore, the

production of a maximum amount of steel for many purposes, which in turn requires the undiminished efforts of every member of the industry. Cooperation and collaboration on the part of users of steel are equally important factors in arriving at the best end results.

Unfortunately we are passing through a period in which the serious cracking of a certain welded ship, or ships, has inspired a vast amount of uninformed comment, and attempts have been made to throw suspicion from one underlying cause to another. There have been evidences of runaway judgment, elaboration of false premises, and a spreading of apprehension through wide circles that "defective" and "substandard" steel has jeopardized the integrity of numerous welded ships. Attempts have been made to lay primary responsibility for the failure of a tanker upon steel which was alleged to be approximately 5% below specified tensile strength. Without weighing the evidence or appraising the facts, spokesmen have declared openly that lives have been endangered and the war effort impaired by the furnishing of steel which was totally unsuited to the purpose of shipbuilding.

This is a regrettable situation, not only because improper deductions are being drawn from erroneous or partial statements, thus diverting attention from the significant factors involved, but also because of the tendency it brings to subordinate reason and judgment to protection against inquisition.

Among the notions which are now abroad we refer, first of all, to the one which charges steel with the responsibility for the failure of the tanker S.S. Schenectady on January 16, 1943. According to specifications, the minimum tensile strength of the plates in this ship should have been 58,000 psi. The particular sheer strake plate in which the crack started, furnished from the Homestead Works of the U. S. Steel Corp., was tested shortly after the casualty by an outside investigator, Prof. S. H. Graf of Oregon State College, who reported values averaging 55,350 psi. at a temperature of 60° F. and 58,600 psi. at 20° F., the atmospheric temperature prevailing at the time of the failure. Additional samples from the same plate, subsequently obtained and tested at room temperature in the laboratories of Carnegie-Illinois as well as by an independent commercial laboratory, gave the following results:

Homestead Laboratory (standard 8-in. specimen): 59,140 psi.
Pittsburgh Testing Laboratory (standard 8-in. specimen): 59,570 psi.

Still another specimen tested in New York under the auspices of the American Bureau of Shipping showed a tensile strength of 56,880 psi.

These data, which are not in full agreement, indicate at least that the unit tensile strength of the steel in question was not more than 4.6% below the specified minimum, if (only for purposes of argument) we accept the lower figures reported by Professor Graf. Now it is hardly necessary to point out that naval architects do not design ships with a margin of safety which would be seriously impaired by any such departure from specified strength.[1] For the important strength-members in a vessel the calculated maximum stresses are related to the specified minimum tensile strength of the steel in the ratio of approximately 3:1 to 4:1. In the case of the S.S. Schenectady, for example, this means that if the steel were actually 2650 psi. below the specifications, such defection would have subtracted approximately 1/15 of the extra allowance for safety. Surely some factors other than the one under discussion must be held responsible for the sudden failure of the tanker, or similar failures elsewhere. Moreover, with respect to the practical bearing of those irregularities in the testing of plates at Irvin Works, recently disclosed and condemned, we assert that unethical as the practice might have been, the safety of ships and the lives of men have not been jeopardized by the inclusion of a small proportion of product which fell below the specified tensile strength by approximately 3000 psi., that is, between 5 and 6%. Such a charge cannot be justified on engineering analysis, metallurgical knowledge, or experience in shipbuilding.

Necessity for Tolerances

In the specification of steel for ships, all parties at interest recognize the value of a set of designated figures, based upon tests, by which to classify the material produced for use as acceptable or otherwise. Some persons would construe the results of tensile tests, for example,

EDITOR'S FOOTNOTES:

[1]Minutes of this meeting indicate that Admiral E. L. Cochrane of the U. S. Navy said that in drawing up its specifications, the Navy must follow some measure of conservatism and yet not be overconservative. Naval architects do not attempt to design to the exact stress, but by means of an elaborate series of calculations attempt to compare the design of a previously successful ship with the design at hand. No steel company should attempt to interpret specifications or read into them a particular problem, Admiral Cochrane said, but he pointed out that the Navy is perfectly willing to discuss specification problems with any representative from the industry. Admiral H. L. Vickery of the Maritime Commission also said that, as far as the tensile strength was concerned, the material would have been accepted from the Irvin Works, had the deviation been reported.

as precise values representing the properties of *every* part of a prescribed lot of steel, to be applied rigidly and not subject to interpretation or modification. We do not in any way belittle the value of tests or the maintenance of standards, but wish to point out that 100% precision and 100% reproducibility are rarely attainable in the testing of steel, and that there is room for the exercise of reason and judgment. One of the Services, recognizing the principle, approves the acceptance of material averaging within the specification, even though single samples may show results 5% below the lower limit. It is unlikely that if this departure were considered critical the material falling on the low side would be accepted. As indicative of an official attitude, we quote the following from a letter of instructions issued early in 1942:

...."It must be recognized, not only by Inspectors but by the building yards to whom copies of this letter are being furnished, that under present circumstances early completion of serviceable ships is of greater national importance than the high measure of perfection required for full durability in peace time....As regards the number of physical test specimens and the number of chemical analyses that are made for all grades of plates procured under the subject specifications, the Bureau authorizes the Inspectors to reduce or waive such tests when, in their opinion, delivery can be expedited and the serviceability of the ships for the present emergency will not be adversely affected....The Bureau is very earnest in its desire to facilitate the manufacture of steel, but desires also to guard the necessary quality of ships upon which some naval action or service may depend."

The precision of tensile testing is affected by such factors as the inherent accuracy of the testing machine itself, by the speed of testing or rate of application of the load, and by the degree of perfection in eliminating minute notches in the edges of specimens prepared for test. Duplicate and quadruplicate samples are used to guard against some of these influences which may affect the results by thousands of pounds. Then there is always the question as to how much material is accurately represented by the samples chosen. An immense amount of work has been done to rationalize this feature, yet provision is made, in many cases, for retesting so that satisfactory steel may not be arbitrarily rejected. Applying the most rigid interpretation, one may say that the results of a tensile test, within the limitations of accuracy of the test itself, measure the properties of only the material in the specimen tested. This is an extreme view, but throws some light upon the problem.

Complete uniformity in steel is highly desirable, yet there are factors which operate toward a degree of non-uniformity, despite the most meticulous efforts in the making, rolling, and heat treatment of steel. Thus arises the need for a practicable *range* in the specification of properties. Segregation of the non-metallic elements in large ingots, such as are used in the production of plates, is not entirely avoidable, and consequent differences in chemical composition lead to the development of differences in tensile properties. The rate of cooling of all parts of a plate after rolling is not entirely uniform, and this too is a well known factor in affecting strength and ductility. Often-times the metallurgist and the inspector ask themselves: "How much of this material logically should be rejected because of a test on a necessarily small sample?"

You in turn may now ask the question: "Why not travel away from the lower side of the specified range and produce material in the upper reaches, safe from falling below the minimum?" The answer is that the allowances of the range are already used, and that material at or slightly beyond the upper limit may be more undesirable than that which falls below the lower line.

In this matter of making steel best suited for the construction of ships by welding there is a conflict of principles. The designer or naval architect wishes high strength, which means high alloying elements, and the metallurgist along with the welding engineer desires good weldability attended by minimum alteration of physical properties, which means low alloying elements. Undoubtedly there must be some give-and-take in this proposition to arrive at the best compromise. Let us not be so sure that the presently specified physical properties are the one best compromise, especially in view of the accelerated pace at which welded ships are being constructed, with the employment of many welders and technicians whose experience is necessarily scant and limited. Considering the margin allowed in ship design between calculated stresses and the tensile strength of steel specified, it is more than probable that dependability in the welded structure would be enhanced, rather than impaired, by the use of steel of somewhat lower tensile strength. This is particularly pertinent to cases in which anything but the very finest welding technique and procedure is used, and there certainly is room to raise the question. In this connection we repeat the earlier remark, that the safety of ships and the lives of men have *not* been jeopardized by the inclusion of a small proportion of steel plates which fell below the specified tensile strength by approximately 3000 psi. With welding conditions as they are, there are those who might logically favor the use of plates of *lower* tensile strength.

The conflict of principles, to which reference was made in the preceding paragraph, is involved again in the matter of the thickness of plates. For example, to set up the specified strength in a relatively thick plate requires more alloying element, such as carbon, than in a thin one. Yet in welding a thick plate there is a relatively drastic subsequent cooling effect, due to the mass of surrounding metal, and a consequent greater hardening effect. In other words, a 1¼-in. plate ordered to 60,000 psi. tensile strength will carry a higher percentage of carbon than a ½-in. plate ordered to the same strength, and when welded will show much more alteration of the metal near the weld than will the thinner plate. One may say that these are metallurgical niceties, but they are related to specifications and to the performance of steel in welded ships, and thus concern all of us because of the situation with which we are dealing. Such considerations raise the question as to whether the shift from riveted to welded construction has been made without giving full weight to metallurgical features and safeguards in welding practice.

In the light of what is happening, and the irrational furor in various quarters about the properties of steel as related to its performance in welded ships, it is not unlikely that we need a renewed understanding of what specifications should specify, and how they should do it. With respect to structural steel for ships, assuming that the design is the same, is the range for tensile strength, 60,000 to 72,000 psi. as specified by the American Society for Testing Materials and the Federal Specifications the correct one, or the 58,000 to 70,000-psi. range of the American Bureau of Shipping, or the 58,240 to 71,680 psi. of Lloyds? Again, is the proper yield point simply one-half the value of the tensile strength or one-half the value but not less than 33,000 psi.? Features of ship design may cancel out these differences, but the steel maker would still like to know, especially in times of unparalleled pressure for maximum output, whether specifications are really specifying actually required and optimum properties for the intended use. There is a community of interest here, intensified by the determination to do the utmost in the war effort.

As a result of the meeting of the advisory committee to W.P.B. at which the above report by Dr. Zimmerman was read, a subcommittee was appointed to review present specifications with the intention of harmonizing them with the true requirements, and to work out a concrete program for later submission to the full committee.

Failure of S.S. Schenectady

By Special Subcommittee
American Bureau of Shipping

THE S.S. SCHENECTADY (503x68x39 ft.) is an all-welded tanker exactly similar in design to ships built and building by the Sun Shipbuilding and Dry Dock Co., Chester, Pa., of which no fewer than 23 have been placed in operation during the past year and which, to the best of our knowledge, have shown no structural defects in service.

The S.S. Schenectady was the first tanker built at the new shipyard of the Kaiser Co. at Swan Island, Portland, Oregon. She had been launched October 24, 1942 and had satisfactorily completed her sea trials. She was lying afloat at the fitting-out dock of the Swan Island yard when, on January 16th, 1943, she broke in two with a loud report, fracturing suddenly across the deck at a point just abaft the after end of the bridge about amidships, the fracture extending down both sides to the bottom shell plating which remained intact. All deck, side and bottom longitudinal frames fractured, as did also the plating of the corrugated longitudinal bulkheads and the centerline deck and bottom girders — thus constituting a complete structural failure except for the flat portion of the bottom shell plating. In no case did the fractures occur in the transverse welds.

The vessel jack-knifed so that the bottom shell plating knuckled transversely and showed above water while the ends of the forward and after sections settled in the silt so that there was a gap of about 10 ft. at the deck. From the character of the fracture the tearing of the side shell appeared to have been more gradual and progressive than the sudden fracturing of the deck from gunwale to gunwale.

The forepeak tank, the forward deep tanks, and the afterpeak tank were full of water as ballasted for the trial trip and there was in addition about 3100 barrels of fuel oil in the cross bunkers immediately forward of the machinery space. The resultant bending moment in hogging in still water was about one-half the maximum design bending moment.

The hourly temperature for January 16th, 1943, shows a high of 38° F. in the afternoon, and 23° F. at 11:00 P.M., the time of failure. The river water temperature was about 40° F. This drop in air temperature of 15° F. over a period of 8½ hr., while not extreme as to suddenness, did introduce a factor in respect of the increased brittleness of steel at low temperature.

It was alleged that the action of the Willamette River had washed a bank of silt under the midship portion and that a subsequent drop of river level had, in effect, caused a stranding. There was no evidence of such a silt formation, and subsequent examination of the vessel in dry dock, by the Committee, disclosed no indication of grounding damage.

Factors Contributing to Failure — After a thorough study of all factors surrounding the failure, including structural design, methods of construction and a complete physical, chemical and microscopic exploration of the material and the welding in way of the fracture, the Committee found the following factors relevant and contributory to the failure:

(a) There was a tendency on the part of the shipyard personnel to depart from recognized fundamentals of good welded construction for the laudable purpose of speeding up construction to the utmost possible extent to meet the needs of the present emergency.

(b) There were insufficient numbers of trained experienced welders and ship fitters available for the job at the rate of production maintained, and an inadequate number of skilled welding supervisors with the necessary knowledge of the basic elements of good welding practice to exercise proper control over the welders.

(c) There was neglect on the part of the personnel to realize the importance of adhering rigidly to established welding procedures and welding sequences necessary to reduce shrinkage stresses to a safe minimum.

(d) There was evidence in the sister vessels under construction of poor fitting of large subassemblies which necessitated considerable forcing into position by the excessive use of jacks and turnbuckles. In other cases open joints required the use of an excessive amount of welding, resulting in excessive shrinkage.

(e) There was a lack of uniformity in the quality of the steel used in the hull structure. For example, as compared with other plates investigated, the particular sheer strake plate on the starboard side where the fracture apparently started had a very low proportional limit[2] (10,000 psi. as determined by extensometer readings on the stress-strain curve); also the Charpy impact values for this plate were low, even at room temperatures, and brittle at 20° F.; the values from the notch bend tests also showed considerable brittleness. It should be recognized that the Charpy and notch bend tests are not included in the ordinary commercial tests by which the quality of structural steel is determined.

(f) A serious accumulation of shrinkage stresses occurred in the automatic machine welding of the deck assembly joints, especially in the longitudinal joint at the gunwale attaching the sheer strake to the stringer plate. This particular welded joint was also found defective in way of the location where the failure started, as evidenced not only by a longitudinal crack but also by what appeared to be minute transverse cracks in the weld.

(g) The hogging moment resulting from the distribution of ballast and fuel in the end tanks produced a tensile stress on the upper flange of the hull girder of approximately 9000 psi., which is comparatively moderate and certainly not sufficient in itself to cause any failure in the hull.

(h) While there is no question with regard to the sufficiency of the vessel's structure, there being no departure from recognized and proven design standards, the abrupt termination of the bridge-end fashion plates at the top of the sheer strake did constitute a serious point of stress concentration especially in a welded structure.[3]

Summary and Conclusion — In the opinion of the Committee the failure of the hull structure of the S.S. Schenectady was due to a combination of unfavorable circumstances. The principal cause was an accumulation of an abnormal amount of internal stress locked into the structure by the processes used in construction together with an acute concentration of stress caused by defective welding at the starboard gunwale in way of the abrupt ending of the bridge fashion plate, augmented by the hogging stress due to the ballasted condition; this accumulation and concentration of stress caused a tensile failure at the starboard sheer strake which was formed of steel of substandard quality, all of which was aggravated to some degree by the drop in temperature.

The procedure immediately recommended and carried out, whereby the defective welding previously referred to was removed from the S.S. Schenectady and sister vessels and these joints properly rewelded, has proven a satisfactory corrective measure as demonstrated by the application of severe bending tests (hogging and sagging). It is the opinion of the Committee that the high stresses responsible for the fractures that have recently occurred in welded vessels were due primarily to the failure to adhere rigidly to the

[2]Professor Graf's report on the steel has never been made public, so the location of the tensile test pieces cannot be stated. If they were taken close alongside the fracture, as is likely, it would be expected that the deformation during the failure would put the material in such shape that it would show a low proportional limit when tested in tension.

[3]This constituted a sharp right angle in the top edge of the ship's plating.

procedure necessary to keep shrinkage stresses within the margin of strength allowed in the design. Steps have been taken with the full cooperation of all yards concerned to insure adherence to proper established procedure and the managements of the yards are fully alive to their responsibilities in the matter. The Committee feels that closer control of welding procedure in which the builders have already been instructed will prevent a recurrence of such major failures. It is also the opinion of the Committee that the probability of fractures resulting from residual stresses in welded construction will decrease with the length of service.[4]

The above engineering report calls attention to the following principal factors contributing to this failure: (1) Abnormal internal stress; (2) Acute stress concentration; (3) Substandard steel of low toughness (notch test).

The third factor has already been considered at length. The second can be corrected in part by changing the contour of certain shapes, but undercut edges and checked and defective welding, as a promoter of acute stress concentration, will be much more difficult to eliminate. Defective welding and improper welding sequences also have much to do with abnormal internal stress, which appears to be the prime cause of the failure, in the Committee's opinion.

What can be done about internal stresses is set forth in the following notable paper by Robert T. Kinkead, read May 14 before the Annual Conference of the Cleveland Section, American Welding Society, and published here by courtesy of that organization:

Residual Stresses in Welded Structures

By Robert T. Kinkead
Consulting Engineer (Welding)

LIKE MOST OF THE PROBLEMS which arise in connection with electric arc welding, residual stresses may profitably be studied in some of the prior crafts of metal working. No small part of the difficulties we have had with residual stresses, and they have been many, come about because the practitioner has come upon the art and science of welding with the admonition that he would be dealing with something wholly new which was so far in advance of anything else that all prior craft could be neglected. I doubt that we shall ever discover anything that will not have its roots in what has gone before.

The most logical place to find prior craft in the matter of residual stresses is in the steel foundry. A steel casting and a welded structure have much in common. The welded structure ends up by being steel, made by rolling, held together by welds which are steel castings. So far as I have been able to find out, and I have had considerable acquaintance among able steel foundrymen, there is no single kind of erratic behavior we have ever known of in steel castings which had not been stress relieved, that has not had its match in welded steel construction which had not been stress relieved. In both cases the structures squirm when being machined, they crack before getting into service, they virtually explode when subjected to impact in cold weather, they fail with a fracture showing that no plastic deformation took place. The erratic part of it lies in the fact that of two apparently identical structures or castings, one will fail and the other will not!

Everyone knows what the steel foundrymen do to overcome the difficulties — they relieve the internal stresses within the castings in a furnace, either as an incident to heat treating or as a separate safeguarding operation.[5]

Stress relieving a welded structure in the furnace does in fact prevent erratic behavior from residual stresses incident to welding. If welding procedure has been such as to leave

[4]In this belief the Committee evidently relies, as does Mr. Kinkead in the following article, on the relief of internal stresses that accompanies slight overstressing (proof stressing) of sound structures.

[5]"Internal stresses" mean a system of balanced forces existing within the body of a structure even though it is not subjected to any working loads. A simple example is a spoked wheel; dangerously large tension stresses can exist in the spokes, anchored at the inner end to a hub, and at the outer end to the stiff, double arch of the rim. Stress relief annealing of mild steel would act in this way: The temperature would be raised slowly to at least 1000° F., that is, into a region where the rigidity of the material is low, so that the "push-me, pull-you" tendencies can actually operate. The material actually creeps, rearranges its atomic configuration, or relaxes locally in such a way that internal stresses are cut down to the low plastic strength of the metal at the high furnace temperature. See *Metal Progress*, February 1942, p. 212.

small cracks or extremely high residual stresses, the structure may crack locally prior to or during the furnace operation. This happens also in steel castings and in both cases proper welding repairs may be made.

We have three other cases to consider, the one in which the structure is of such a shape as to permit easy mechanical stress relief by loading, another in which the structure is so large that it cannot be put in a furnace, and lastly the welding techniques designed to prevent high residual stresses.

A cylindrical or spherical tank made up of welded components is easy to stress relieve by internal hydraulic pressure in excess of the working pressure, and this method is approved by the A.S.M.E. Code for certain classes of unfired pressure vessels. In the vessels having heavy plate and of a class the failure of which would cause death and great destruction, stress relieving in the furnace is required. Many welded structures for mechanical purposes are effectively stress relieved by loading applied by hydraulic cylinders, by application of weights or otherwise producing unit stresses greater than the working load. What happens is that metal which is already highly stressed incident to the welding operation simply passes through the yield point into the plastic range, and deforms locally, thus dissipating the local residual stress.

A large oil storage tank, a bridge or a ship represents the case of the structure being too large to get into a furnace. But here the solution to the problem of eliminating erratic behavior may be worked out along the same lines that have been proven in pressure vessels. An oil storage tank is required to be filled with water. This will stress the structure slightly beyond its normal unit stresses when filled with oil and stress relieve it very effectively. A bridge may be loaded with whatever is the most convenient, such as water tanks or sand bags. A ship may be loaded with water in her ballast tanks.[6]

Some structures may be stress relieved by their first service loading. This requires the exercise of considerable judgment; the important question which arises when no previous experience is available is related to the design of the structure itself and whether residual stresses might cause disastrous failure on first loading. A welded crane girder as now commonly designed illustrates a structure which is not likely to fail on first loading regardless of residual stresses. A poorly designed ship represents a structure which may fail on first loading in service.

The temperature at which first loading is applied whether service loading or for the purpose of stress relieving will have an important effect. Thus a large crane shovel boom of welded construction given its first loading in zero weather may fail in the plate due to residual stresses and low impact resistance of mild steel at low temperatures.[7] There is always a certain amount of "snapping" and violent readjustment of a welded structure which has not been stress relieved, when the first loading is applied. This sets up impact stresses which at low temperature in combination with residual and loading stresses are likely to cause failure.

The plan of using a technique to prevent high residual stresses incident to welding is most interesting. Early in the history of welding ships in this country the U. S. Navy adopted a formula for manual welding of ships which has stood the test of time. It is simple: "Start welding amidships, weld outboard, fore and aft, up and down, always stepping back." While it is difficult to weld up, stepping back towards the centerline — and I do not believe much of it is done — the procedure is sound, and when the additional requirement of keeping the welding balanced on the hull is followed, it works out effectively.

"Stepping back" is a procedure which was taken directly from the prior craft of riveting. The practice does effectively limit the degree of transverse residual stress but it does not affect the degree of longitudinal stress incident to the welding operation.

Peening weld metal as it is applied and after both weld and plate have returned to ambient temperature is entirely effective in reducing residual tensile stresses. The only valid objection to the practice is its cost.[8]

From the engineering point of view we would seldom rely for safety on the assumption that *any* of the procedures designed to prevent or progressively reduce residual stresses had actually done so. There are too many doubts about whether a procedure was followed and the result actually attained. If the structure were of the type which

[6]Ballasting end tanks will relieve dangerous concentrations of longitudinal tensile stresses in the upper members of the hull, which act as the tension flange of a long beam, either by plastic action (which is to be desired) or by fracture (which can be repaired). Relief of dangerous tension stresses in a fore-and-aft direction at or near the keel and bilge can be similarly corrected by central ballasting or loading after launching.

[7]Mr. Kinkead might also have mentioned as a major cause the likely existence of minute fractures (stress raisers) either in the weld metal or in the heat-hardened base metal alongside the seam.

[8]And the impossibility of knowing how much peening is necessary.

should be stress relieved by preliminary loading before putting into service, we would apply the load regardless of the manufacturing procedure. In this event peening or whatever method was applied would be so much waste of time, insofar as residual stresses are concerned. Correct procedure and sequence of welding are matters of importance in the welded assembly to prevent cracks which would otherwise occur, and to avoid excessive deformation during fabrication.

Since modern practices have been followed I have never seen a structure, relieved by mechanical loading at a temperature above 45° F., fail where the cause could be clearly shown to be primarily residual stresses. I have seen structures fail for other causes under such loading, but when the structure fails under these conditions no one gets hurt. The break is repaired by welding and retested. Likewise a break on proof loading has a salutary effect on the personnel.

Taking into account the physical properties of the steel in large structures and those of the weld metal, it is difficult to conceive how residual stress could cause failure under *static* loading. Leaving armor plate out of consideration, weld metal has a higher yield point than the mild steel plate commonly welded. No one would intentionally apply a load which would produce unit stresses above the yield point of the steel.

The purpose in removing or greatly reducing residual stresses is to protect the structure against failure due to reversal of stress, impact, and erratic behavior due to bi-axial and tri-axial stresses.[9] In dealing with the safety of the structure we are not concerned with whether failure originated in the weld or in the plate which has residual stresses incident to the welding, as long as both plate and weld are sound. Unless the structure as a whole behaves under service loading exactly as if it were all one piece and made of the steel specified, its behavior is unpredictable. It will be unpredictable under the types of loading mentioned above so long as residual stresses are a factor in its behavior.

It is a fact that we have no non-destructive method of evaluating residual stresses in a structure. Even experience in building a number of identical structures of large size is unreliable. We can never be sure that the procedure and sequence were identical.

The way in which we deal with residual stresses in welded structures to make the structures safe is based on a vast amount of practical experience in prior crafts of metal working as well as on the experience of large numbers of able men who have built large welded structures successfully for many years. We are now in the most desperate and frightful struggle in our Nation's experience and the need for large welded structures is first on the list of urgency. Vast numbers of new and previously inexperienced personnel serve as workers and as supervisors and even engineers. It is to be expected that errors of judgment will be made, they undoubtedly have been made and will continue to be made. These things are just as unavoidable as the loss of brave and gallant officers and men on the field of battle due to their inexperience as soldiers. If the information I have is correct, the number of failures of large welded structures due to residual stresses, causing loss of life, is so small as to be one of the lowest hazards of the war. We will not know the whole story until after the war is over, and perhaps not then. Nevertheless, I have undertaken to give a general overall picture of methods of dealing with residual stresses in the hope that it will be useful to those who are responsible for making welded structures safe from failure due to these causes.

Lest it be imagined that these problems in ship building and ship sailing were unknown before the welded hull, these articles may be ended with quotations from "The Ship That Found Herself", written by Rudyard Kipling before a welded ship was even dreamed of:

The skipper said to the engineer, "The parts of the new ship have not learned to work together yet.... Every inch of her has to be livened up and made to work with its neighbor.... Our new little ship has to be sweetened yet and nothing but a gale will do...."

"Rigidity! Rigidity! Rigidity!" thumped the engines.

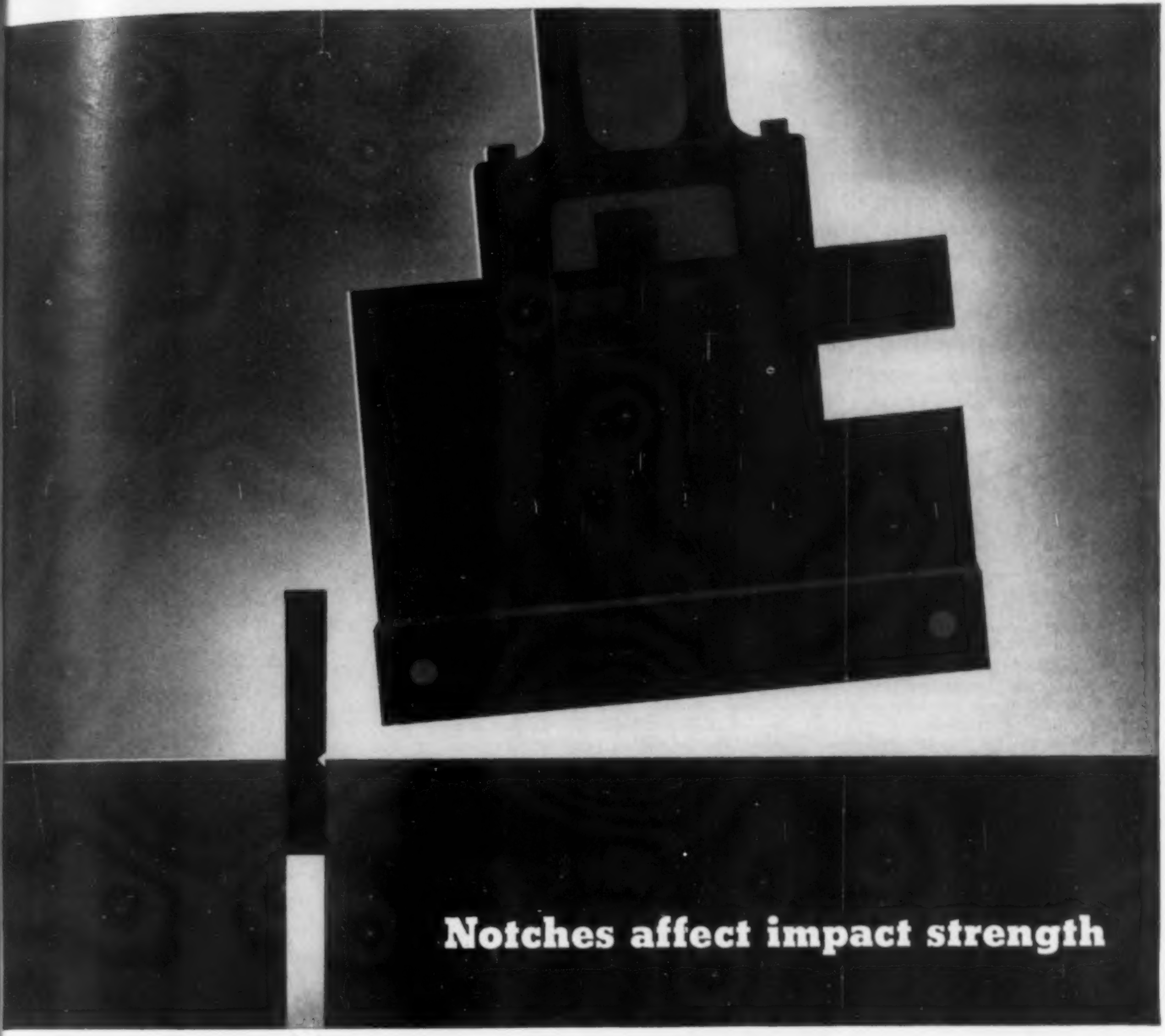
"Ease off!" shouted the forward collision-bulkhead. "I want to crumple up, but I'm stiffened in every direction. Ease off, let me breathe!"

All the hundreds of little plates that are riveted to the frames echoed the call, for each plate wanted to shift and creep a little, and each plate, according to its position, complained against the rivets. "Theoreti-retti-retti-cally rigidity is the thing. Purr-purr-practically, there has to be a little give and take." ....

And later, after the gale, there was just as much groaning and straining as ever but it was not so loud or squeaky in tone, and when the ship quivered, she did not jar stiffly, like a poker hit on the floor, but gave with a supple little waggle, like a perfectly balanced golf-club....

For when a ship finds herself, all the talking of the separate pieces ceases and melts into one voice, which is the soul of the ship.

[9]See "Addendum on Tri-Axial Stresses", p. 946.



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Personals

Thomas N. Armstrong ⊕, metallurgist with the development and research department of the International Nickel Co., is now also a part-time member of the staff of the War Metallurgy Committee of the National Academy of Sciences, National Research Council.

Ralph N. Fitzpatrick ⊕, formerly alloy foundry metallurgist of the Midvale Co., Philadelphia, is now a sales engineer for the Electro Metallurgical Sales Corp., New York City.

Earl S. Patch, formerly an executive of the Moraine Products Division of General Motors Corp., Dayton, has been appointed sales manager for Henry L. Crowley & Co., Inc., West Orange, N. J.

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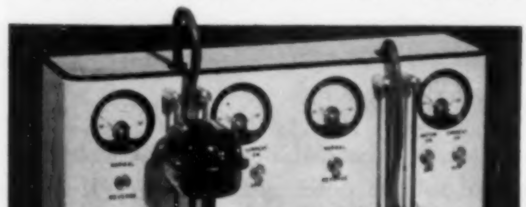

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SCIENTIFIC LABORATORY SUPPLIES

Harold F. Haase ⊕ has been appointed to the staff of Battelle Memorial Institute, Columbus, Ohio, to engage in electrochemical research.

F. R. Morral ⊕ has resigned as assistant professor of metallurgy, Pennsylvania State College, to take an industrial fellowship at Mellon Institute, Pittsburgh.

Michael Chiovare ⊕, formerly die hardener, Automatic Electric Co., Chicago, is now tool and die hardener, Dodge Chicago Plant of Chrysler Corp.

G. B. Kiner ⊕ has transferred from assistant chief metallurgist, International Harvester Co., Fort Wayne Works, to chief metallurgist at the St. Paul Works.

George H. Thurston ⊕ is now a captain in the U.S. Army, serving as battery commander somewhere in Alaska.

H. L. Frevert, formerly president, has been made chairman of the board of the Midvale Co., Philadelphia. **Francis Bradley** becomes president, and is replaced as vice-president by **George E. Smith**, general superintendent.

Awarded the medal of the American Institute of Chemists: **Walter Savage Landis**, vice-president of the American Cyanamid and Chemical Corp.

Everett Chapman ⊕ has resigned as president of Lukenweld, Inc., Coatesville, Pa., to establish his own consulting engineering business. Administration of Lukenweld will be in charge of **G. Donald Spackman**, who was recently elected vice-president in charge of operations at Lukens Steel Co., the parent organization.

A. John Erlacher ⊕, formerly a welder for Sun Shipbuilding and Drydock Co., is now methods engineer for Welding Engineers, Inc., Norristown, Pa.

G. F. Hocker ⊕ has been appointed Government presiding officer of the Commercial Drop Forging Industry Advisory Committee to War Production Board.

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Blast Furnace Refractories*

By Raymond E. Birch

THE MODERN blast furnace imposes severe conditions on the refractory linings. Nevertheless, improvements in the brick themselves have greatly increased the life. Shaping the brick in a vacuum has decreased the porosity, which helps them resist abrasion, gas penetration, and slag attack. Pressure cracks do not develop in power pressed brick if vacuum is applied to the loose clay just before the brick is pressed. This led to the Hendryx plan for withdrawing the air in the fraction of a second within a normal pressing cycle.

Service Factors — The requirements for bricks in the various furnace zones are not the same. (Uniformity of size is equally important at all locations.) Abrasion is a factor of real importance just below the wearing plates and in the remainder of the inwall. However, in developing the standard blast furnace refractories, *toughness* has been sought rather than hardness. Regardless of improvements in brickwork, the bosh must always be water cooled.

Carbon Disintegration — One of the important enemies of linings is disintegration caused by the deposition of carbon within the pores of the brick. Apparently a reaction takes place between carbon oxides (absorbed by the brick) and the metallic oxides contained in the clays. Some blast furnace brick are given a reducing burn to convert the iron oxides to magnetite and thus render them less active as a catalyst. Furthermore, it was learned that harder firing caused the iron oxide to combine with alumina and silica, where it is not an active catalyst for the reaction depositing carbon.

In bricks which resisted disintegration each part of iron oxide had apparently combined with 1¾ parts of aluminum plus silica, while in those which disintegrated the iron oxide had combined with less than ½ part of alumina plus silica. A reducing burn at high temperature is needed to bring about the desired silicate formation. Even firing temperatures just a little beyond those ordinarily used in the past greatly improve blast furnace brick in this respect.

These high-fired refractories are available in two forms:

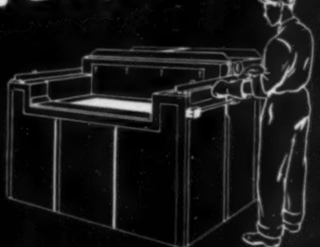
1. Brick made from standard blast furnace mixes fired at higher than normal temperatures.
2. Super-duty fireclay brick made in Kentucky and Missouri.

(Continued on page 934)

*Abstracted from *Engineering Experiment Station News*, Ohio State University, October 1942, p. 12.

LIQUID CARBURIZE IN CYANAMID TWO COMPONENT BATHS

AEROCARB*



AEROCARB DEEPCASE
AEROCASE*

Cyanamid pioneered and for many years has been the sole advocate of the two-component type of liquid carburizing baths. Aerocarb and Aerocarb Deepcase, more recent developments of our laboratories, incorporate in their formulation the knowledge and experience gained over more than twenty years of laboratory investigation and industrial experience. Only two components can provide the ease of control and chemical stability necessary under the difficult conditions encountered today in war plants where deeper cases, longer time cycles and smaller drag-out losses have resulted in many bath failures.

Former exponents of single material baths are recommending two components for applications in which their standard single material had failed under today's exacting conditions. But two components alone are not the solution to liquid bath operating difficulties. Cyanamid's careful selection and preparation of materials and intelligent formulation are necessary to provide baths that are unmatched in stability of bath composition, uniformity of penetration and quality of case.

Let us *prove* this statement through the operation of a Cyanamid two-component bath in your plant. The experience of a technical staff and the facilities of our laboratories are at your disposal to assist in the solution of your case hardening and carburizing problems.

AMERICAN CYANAMID
& CHEMICAL CORPORATION
A Unit of American Cyanamid Company
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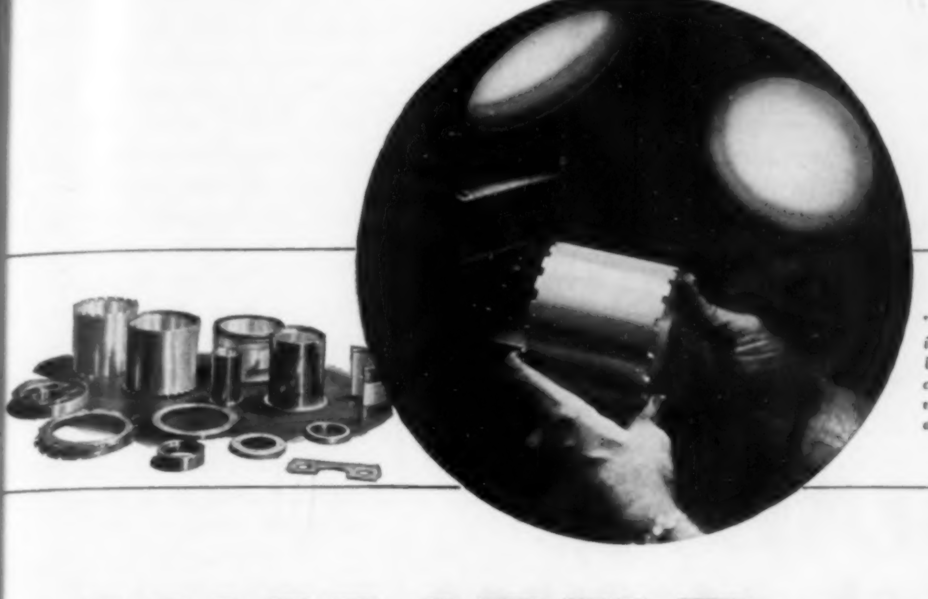
*Reg. U. S. Pat. Off.



"Black Light" testing makes certain the bond is perfect on edges of all Mallory Bearings. Under its magic rays, microscopic voids and cracks show up by fluorescence. A filter cuts out visible radiation from the "Black Light", allowing only ultra-violet radiation to pass.

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Mallory Bearings are made by Mallory's Mallosil Process of bonding silver to base metal backings. They provide a tough, homogeneous, heat dissipating silver surface of high fatigue resistance; ample strength and hardness; and high resistance to seizure.

What is more, Mallory Bearings are precision made. Through use of newly designed precision tools and test instruments, skilled Mallory craftsmen have set remarkable records for exactness and uniformity in producing bearings, bushings, pinion races, gear races and other aircraft engine parts. With tolerances measured in split-thousandths, they are turning out ever-increasing quantities of precision parts with an accuracy and uniformity considered impossible only a few short months ago.

Continuous experimental designing and testing indicate even greater results for the future. The experience and technique gained in War production will be invaluable for commercial motors development when Peace has arrived. Consult us on the possibilities of the Mallosil Process for you.

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Refractories

(Continued from page 932)

Their outstanding properties include high spalling resistance, high temperature volume stability, low porosity and high refractoriness. Their resistance to carbon disintegration depends upon the way they are fired.

A deficiency in the super-duty fireclay brick now being tried is their high permeability.

The Alkali Problem — The big question mark in the whole problem of improving stack life is the effect of alkaline elements. Hardness of burn is probably of no great importance in this connection. Even low porosity cannot do more than retard the soda-bearing vapors. The property of permeability to gas penetration could be far more important than porosity.

W. Rex McLain has found that alkalies alone, without the aid of deposited carbon, can completely disrupt blast furnace stack refractories. His conclusions are worth restating:

"1. The inwall lining of a blast furnace stack, about 20 ft. up from the mantle, may be expected to disintegrate because of alkali pick-up and the formation of nepheline.

"2. The most severe disintegration corresponds to the greatest alkali increase.

"3. Neither the conversion of iron oxide to Fe_3O_4 nor FeO nor the elimination of iron oxide from the clay will prevent carbon disintegration because 1 to 2% of iron is absorbed by the brick during its service."

Lining failures from zinc condensation have also been noted.

Importance of Design and Installation — Today's blast furnace is a well-balanced machine of high efficiency. In the past, the refractories suffered when the designer modified the design without regard to the capabilities of the building materials. For instance, the trend to wider hearths penalized the refractories in the stack since it was not realized immediately that the diameter at the stock line needed to be increased also. Again, faster melting rates increased gas velocities in the stack and caused channeling. On the other hand, recent improvements in design and greater uniformity of the charge have benefited the lining.

Further improvement in the refractories may be looked for, but details of their installation and care may turn out to be even more important. Use of strong bonding, high temperature cements in the brickwork just under the wearing plates is becoming standard practice. The importance of thoroughly drying out the furnace, and particularly the bottom, cannot be overemphasized.

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HIGH ALLOY CASTINGS

. . . of any size up to 4 tons.

. . . of any combination of chromium, nickel and other alloying elements.

. . . made in a modern foundry with complete facilities.

. . . backed by an experience dating back to 1922 for static castings; and back to 1931 for centrifugal castings.

That, in a few words, is what DURALOY has to offer industry. It is as much as any high alloy foundry can offer and more than most.

And *experience* is probably the most important item on the list. Bear it in mind when in the market for high alloy castings.

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Chromax*

Limitations† on certain uses of chromium-nickel iron alloys for heat resistant purposes restricts the use of Nichrome (HW). In order to save vital nickel and chromium, it has been determined that an alloy such as Chromax (HT) will suffice during the emergency for applications such as carburizing, salt and lead pots, quenching fixtures and the more severe uses. To get the best from this alloy, it must be cast properly. We at Driver-Harris Company can do just this.

†See W.P.B. Supplementary orders M-21-g.

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*Trade Mark Reg. U. S. Pat. Off.

Beryllium

(Continued from page 907)

manufactured but the cost would be high. The availability of aluminum base beryllium alloys for major items of aircraft or engine construction cannot be seen around the corner and should not be viewed as a wholly probable short-time outcome of present efforts in this direction. The Army Air Forces (Wright Field) and the War Metallurgy Committee have encouraged research on aluminum-beryllium alloys in the past and have recommended that experimental work be continued because of the chance that, for one or more special war applications requiring relatively small amounts of material, the aluminum-beryllium alloys may show outstanding superiority.

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Ask for Bulletin 1012-6A and about Sentry Furnaces.

Sentry "Always on Duty"

The Sentry Company
FOXBORO, MASS., U. S. A.

Beryllium Oxide Refractory

Beryllium oxide, fired to be used as a refractory material, is extremely strong and hard and very resistant to thermal shock. Of major importance is its melting point of 2570° C. (4660° F.) which is about 500° C. (900° F.) higher than that of alumina. Moreover, beryllium oxide in combination with other oxides seems to confer upon the mixture its own quality of electrical resistance at high temperatures.

In spite of its high thermal conductivity, but because of its great stability, finely divided beryllium oxide is an excellent heat insulator for high temperature furnaces and especially for high frequency insulation where electrical conductivity may be undesirable.

Beryllium Phosphors

Beryllium oxide is the most important fluorescent material used in lamps. Materials having the property of transforming radiation of a given wave length into radiation of longer wave length are now referred to as "phosphors". Beryllium phosphors are used in about 92% of the present production of lamps and are also used in smaller quantities in X-ray screens, television and other cathode-ray tubes.

One pound of beryllium oxide is sufficient for more than 400[illegible] fluorescent lamps. About 10,0[illegible] pounds of beryllium oxide annually will be needed for phosphors.

The best substitute now known for beryllium as a phosphor is cadmium. Besides requiring 18 times more cadmium oxide than beryllium oxide, the initial light output is 20% lower, and the maintenance of initial light output is only 73% of that of the beryllium phosphor at the end of 500 hr. It will therefore be preferable to pay considerably higher prices for beryllium phosphors than to use cadmium. Large savings in the consumption of electrical energy result from this minor use of beryllium oxide.

Forge Plant of The Steel Improvement & Forge Co., January, 1943

by FORGING

Throughout 30 years of venturesome technical and production effort, marked by one plant expansion after another, this forging organization has invariably utilized the exact forging techniques required, to obtain the utmost improvement of metals by forging. Adapting a broad experience, with exacting forging techniques, to the production of forgings for war, is our whole duty today.

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FORGINGS **958 East 64th Street** **CLEVELAND, OHIO**

Openhearth

(Continued from page 903)

To avoid such defects it was recommended that nozzles be large enough to allow metal to overtake shells before they become oxidized or cold, and that stop pours near the bottom of the ingot be avoided.

Boron as Alloying Element

Boron has emerged from the experimental stage as an alloying element. Operators were told that its effects in increasing hardenability were at a maximum when 0.003% is present. Further additions up to 0.007% have no value, and beyond this amount trouble with hot shortness may be expected. When ferroboron is used for ladle additions, best results have been obtained by adding it after all other deoxidizers. Fine grained steel (and thus thorough deoxidation) is necessary for its successful use as an alloy.

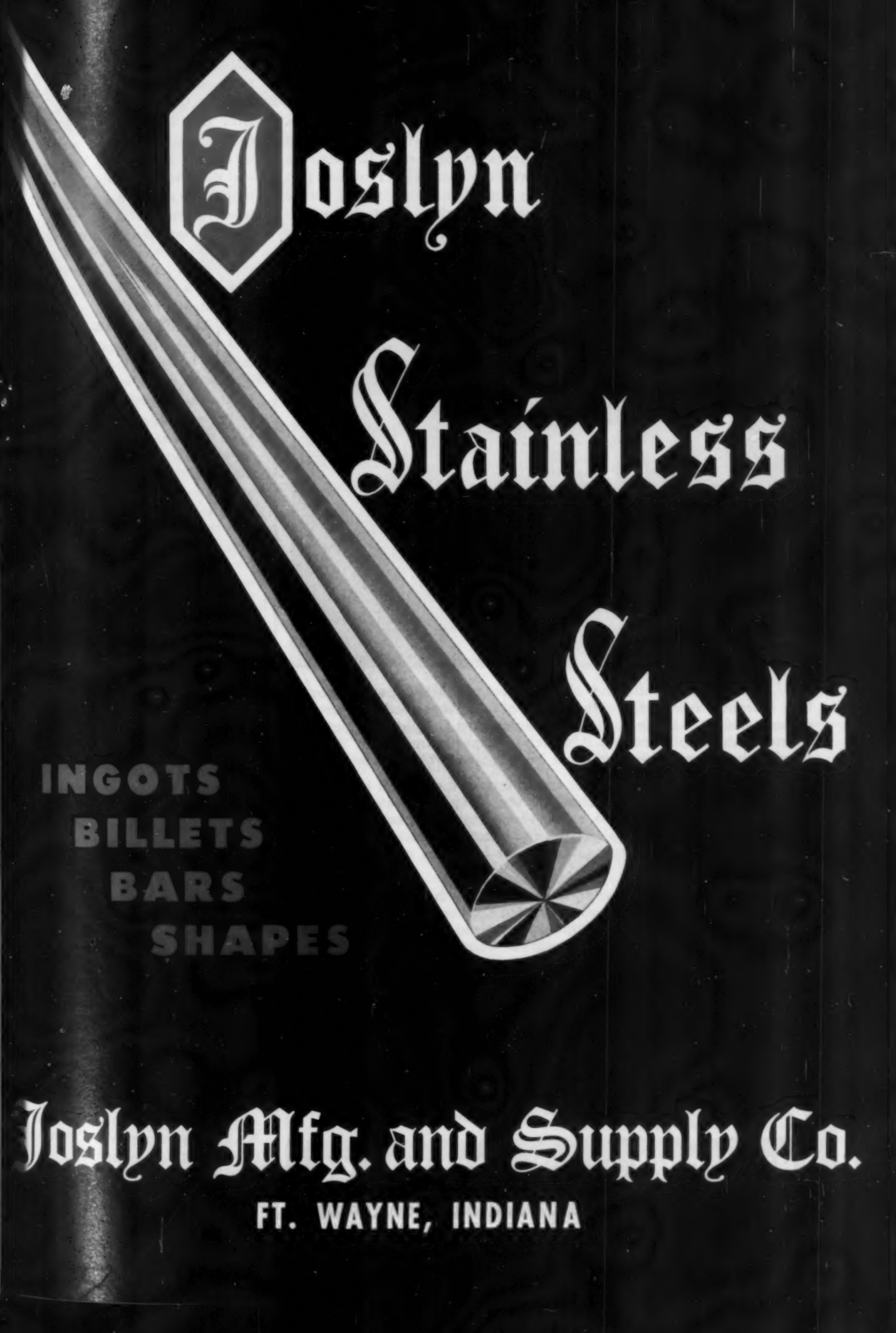
Analytical Improvements

Use of the spectrograph for analysis of residual alloys in scrap and openhearth baths is becoming more widespread. G. T. Motok stated that five elements can be reported within 30 min. after the sample is received. A. D. Beers reported that 18,000 determinations for residual elements had been run by one spectrograph during a single month. Aside from this practical value, the spectrograph is also creating important savings in chemical research.

Mr. Motok also described a simple method for sampling molten steel. The apparatus consists of a glass tube which is fitted with a rubber bulb at the cool end. The bulb is compressed and the tip of the tube inserted into molten metal. When the bulb is released, metal is sucked into the tube and a long solid pin of the type desirable for spectrographic analysis is obtained. Investigation proved that no contamination resulted from the glass tube, which remained unmelted after sampling.

Steel Plant in California

The new steel mill being erected by H. J. Kaiser at Fontana, Cal., was described in detail. This will be a complete plant with coke ovens, blast furnace, five 185-ton openhearths, and plate mills. It is estimated that ingot production will reach 675,000 tons annually. Plates will comprise the bulk of the finished product; they will be rolled direct from ingots so no blooming mill has been installed. Facilities for mold preparation and pouring are exceptionally complete because it is anticipated that most of the ingots will be bottom poured.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Addendum on Tri-Axial Stresses

By The Editor

IN ORDER that "tri-axial stress" may not be merely another name for something one doesn't understand, the following explanation is ventured: A ductile metal will deform plastically, prior to fracture, and metallographers can prove that such deformation occurs by slip of one portion of a crystal past another. In other words, the tensile stresses are "resolved" along lines and directions which cause slight movements in shear. If, now, the particles of metal were so held that slip movements (shear) were impossible, these particles would theoretically then be acted upon by balancing forces in the three co-ordinate directions. They would be held by "tri-axial" forces; failure would occur by tearing of atom from atom, bond from bond, without signs of "ductility", so called... How can such a failure occur in everyday life? Suppose a penstock is rigidly anchored at both ends, and filled with water. The internal hydraulic pressure will cause the pipe to enlarge in diameter, and the necessary metal for this enlarged circumference would normally come from a shortening of the pipe, just as a snaky garden hose is straightened out when the pressure is on. But this penstock is anchored and cannot shorten. Disastrous failures have been recorded under precisely those conditions; the fracture is associated with no ductility, no reduced section. It is a case of tri-axial loading. Yet the metal of the pipe, tested in tension in the usual way either before or after the disaster, will show normal ductility. The trouble is not defective metal, but defective construction; the penstock was too rigid for its own good....Any ductile metal can be made to break in a tension test with a coarse crystalline fracture and without "ductility" (necking down) if the metal at the surface of the test piece be prevented from flowing inward, as it would normally, between the elastic limit and the ultimate strength. How this is done is described by Maxwell Gensamer in *Metal Progress*, July 1940, page 59. He notches a round tension test piece, and runs it in a rotating fatigue machine until a tiny surface crack extends clear around the specimen, leaving a central core still unaffected. Then this specimen is pulled in tension. The metal at the very edge of the central core would normally move inward, to form the ductile neck; however, it is prevented from doing so by being rigidly attached to the double arch or hoop of exterior metal. The result is a coarse crystalline, brittle fracture in what is normally thought of as ductile metal. . . . Of course, you may say: "But you have then the effect of a sharp crack, and everyone knows a sharp crack is a stress raiser." To that the reply is that you have unwittingly given another practical instance of how tri-axial stresses can occur in everyday life.

(Refer to page 926)

Successful production of alloy steel castings depends upon: (1) a thorough knowledge of the nature of the alloys used, (2) correct design, and (3) extreme care in the preparation of molds, regulation of temperatures, pouring, etc. It is a job for experts...men with "know how"... because, each step must be handled with extreme care.

For twenty years Cooper has operated one of the largest foundries in the country devoted exclusively to the casting of alloy steels... stainless steel, monel, nickel, chrome-iron, chrome-nickel and other special alloys ... for corrosion, heat and abrasion resistance. Today, we are pouring more castings than ever before in our new, completely modern plant.

Cooper specialists will be glad to assist you with design problems and the selection of the best alloy for your application. We'll be glad to send you a new data sheet giving analyses, characteristics and applications of Cooper standard alloys. Write for it today.

THE *Only* ALLOY FOUNDRY WITH *All* THESE FACILITIES

- Laboratory control over raw materials and finished products.
- Dual foundry...both hand and machine molding.
- Heat treating of castings up to six feet in size.
- Machine shop . . . specially equipped for finishing stainless steel.
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- Castings furnished rough, polished or fully machined . . . one ounce to two tons.
- Development of special alloys to meet unusual requirements.
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In this war of metals the Commercial Heat Treater's status is truly "specialist". So varied and unpredictable are war's demands that new heat treating techniques must be devised, new methods adopted, new equipment added.

The result — a growing wealth of knowledge and experience, a store of new, modern equipment and facilities that will bring actual dollars-and-cents benefits to peacetime manufacture.

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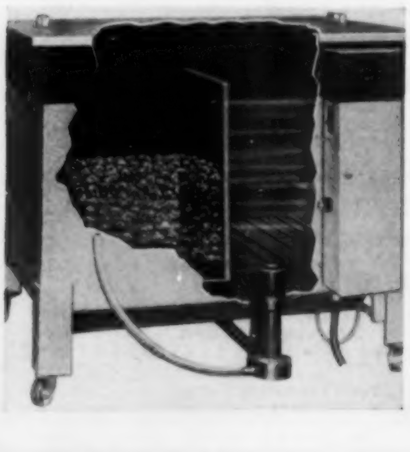
New Products

and Machinery

New Degreasing Unit

A portable degreasing unit which includes a pre-dip wash and vapor rinse and dry has been added to the line of the Phillips Mfg. Co., 3419 Touhy Ave., Chicago. This small, double-dip, manual machine has been designed particularly for small metal parts whose light gage makes them unsuitable for handling in the conventional vapor degreaser, because insufficient vapor would condense on their surfaces to thoroughly rinse off oils or waxes.

The pre-dip wash recommended by Phillips consists of a kerosene-solvent solution, to which is added a very potent wetting agent. This has the quality of thoroughly emulsifying oils, greases and waxes so the solution will thoroughly flush them off the parts before the latter are transferred over into the vapor compartment.



Grease-Squirter

A new device for automatic application of controlled volumes of lubricants, ranging from light oils to heavy fibred greases, to the bearings of conveyor trolley wheels is announced by the J. N. Fauver Co., Detroit. It is particularly handy for conveyors which pass through kilns, ovens, dryers and other hot zones, where proper lubrication is difficult.

Box-Type Furnace

New box-type furnace suitable for heat treating at continuous temperatures up to 2000° F. has been added to line built by H. O. Swoboda, Inc., Thirteenth St., New Brighton, Pa. Chamber dimensions range up to 30 in. square by 4½ ft. deep. Furnace is heated by electric resistors and is equipped with movable loading platform for charging and discharging, and features a push-button controlled, motor-operated mechanism for opening and closing the door.

Shear-Hardness

A shear-hardness attachment for the Taber Abraser is now offered by Taber Instrument Corp., North Tonawanda, N. Y., which measures the "toughness" of surface finishes and their ability to resist digs, scrapes and similar abuse from actual service not considered normal wear.

In use, a weight slides along the calibrated beam until it is finally located in the position where the correct load permits

the tool point to cut a groove in the surface finish without digging through to the base plate. Several grooves are made and the most representative selected and measured by a special micrometer. "Shear hardness" is taken from a tabulation, using the experimental data *(a)* load and *(b)* width of groove.

De-Burring Equipment

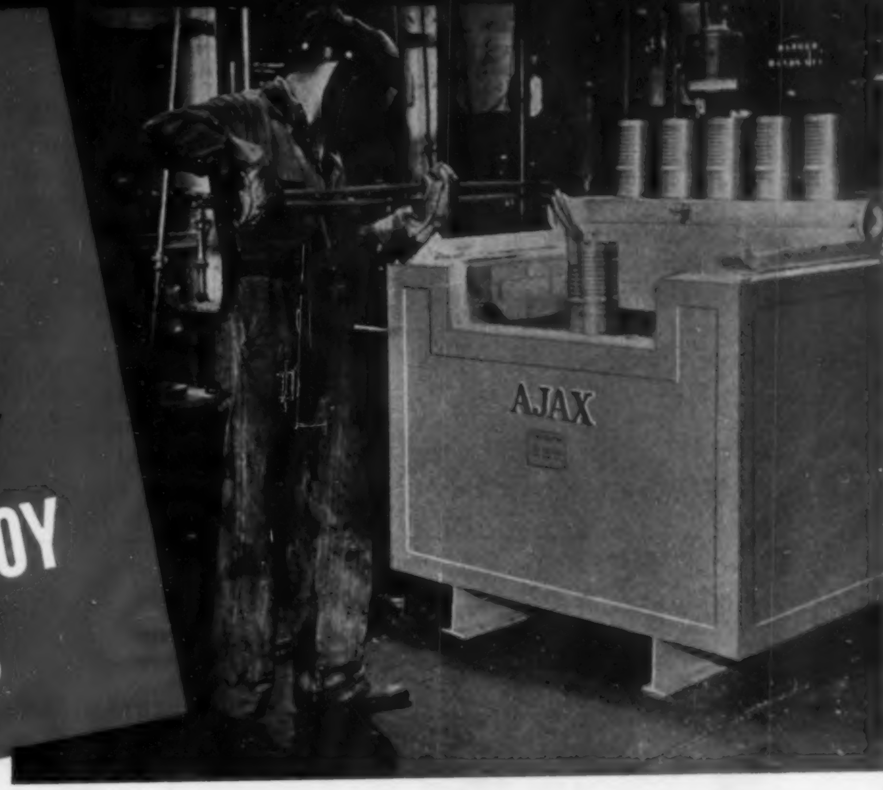
"Roto-Finishing" is a new method, adaptable for fine precision work on parts for airplane engines, machine guns, and many other war parts whereby small or medium-size parts may be de-burred, buffed, polished and colored, either before or after plating. Die marks and machining marks, rough, sharp edges or

(Continued on page 964)

y Salt Baths are E LOGICAL WAY TO HARDEN

ITHOUT DECARB OR SCALE ✓
WITH MINIMUM DISTORTION ✓
AT FASTEST HEATING RATE ✓

CARBON AND ALLOY STEEL PARTS



Immersed in the salt bath at 1550 deg. F. and quenched over a mandril in oil, big cylinder sleeves shown hold diameters to .007" at output speeds of 120 in 8 hours, using the 65 kilowatt Ajax-Hultgren furnace illustrated above.

An Ajax-Hultgren furnace is the *logical* way to harden, because:

1. In hardening, a neutral molten bath "controls the atmosphere" by the simple process of eliminating it entirely. A salt film seals out deleterious gases right up to the instant of quenching, hence decarburization, oxidation, or scaling *cannot* occur. No other heating medium possesses this valuable characteristic.

2. A salt bath is the fastest heating medium for transferring heat to work. Therefore, an Ajax furnace will yield more completed heating cycles per day than any radiation or forced convection system.

3. Heating in an Ajax-Hultgren furnace is uniform at all points, hence distortion does not occur. This feature—based upon absolute and automatic temperature control—is an inherent characteristic of the furnace, and no other means will provide such temperature control and uniformity of heating within such narrow limits (5 deg. F. or less).

4. All forms of hardening in an Ajax-Hultgren furnace may be done selectively, as desired. This feature itself is only a partial demonstration of the great flexibility of these units as used in industry today.

It is only logical to find that there are now more than a thousand Ajax-Hultgren Electric Salt Bath Furnaces in use* for . . . hardening armor plate, armor piercing shot, dies . . . aircraft structures, steering gear assemblies, ordnance components, gears, high speed steel tools (up to 2400 deg. F.), etc.

If you have not yet investigated Ajax-Hultgren applications, send at once for Catalog 107-A. It describes manual and mechanized installations, from 35 to 750 kilowatts in size.

HERE ARE THE KEY PROCESSES TODAY...

- CARBURIZING
- SIMULTANEOUS BRAZING & CARBURIZING
- NEUTRAL HARDENING
- CYANIDE HARDENING
- SELECTIVE HEATING
- AGE HARDENING
- TEMPERING
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- ANNEALING
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- HEATING FOR FORGING

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THE AJAX HULTGREN ELECTRIC SALT BATH FURNACE

SELF-HEATING · SELF-CIRCULATING

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AJAX ELECTROTHERMIC CORPORATION, *Ajax-Northrup High Frequency Induction Furnaces*
AJAX ELECTRIC FURNACE CORPORATION, *Ajax-Wyatt Induction Furnaces for Melting*
AJAX ENGINEERING CORPORATION, *Ajax-Tama-Wyatt Aluminum Melting Induction Furnaces*

New Products

(Continued from page 962)

corners, are removed. Roto-Finish is available in either the wet or dry process, and is manufactured by the Sturgis Products Co., Sturgis, Mich., and distributed by Frederic B. Stevens, Inc. of Detroit.

The wet process is especially adaptable for handling heavy gage stampings, large or irregularly shaped parts, or where a particularly smooth bright finish is required.

The dry process is better suited for brass castings, light gage steel and brass stampings, and die cast pieces before plating. Through an abrasive action of the dry finishing compound, surfaces are smoothed and given a fairly bright finish.

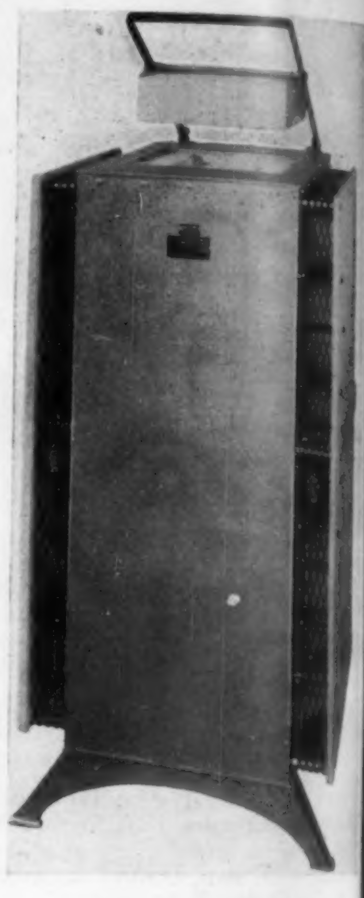
DETROIT
Melting Furnaces for Precise Metallurgical Control

For close chemical and metallurgical control of any desired ferrous or non-ferrous alloys, the Detroit Rocking Electric Furnace with its exclusive, automatic stirring action under non-oxidizing conditions simply cannot be beaten. You can run a different mixture on each subsequent heat or the same alloy all day long with remarkable uniformity. Write today for complete facts about this fast melting, efficient, labor saving, money making foundry tool.

DETROIT ELECTRIC FURNACE DIVISION
KUHLMAN ELECTRIC COMPANY • BAY CITY MICHIGAN

Hardening Furnace

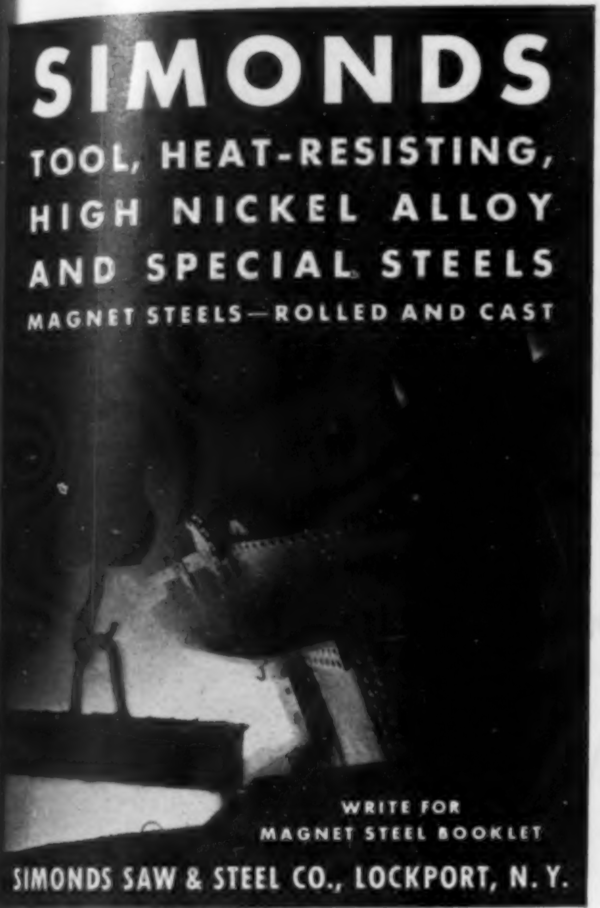
New and larger electric vertical furnace for high speed steel hardening is announced by the Sentry Co., Foxboro, Mass. Well insulated, it will attain a top temperature of 2500° F.; recent tests



have shown a heating time of 75 min. from room to 2350° F. Equipped with Globar heating elements, the full muffle chamber is made of silicon carbide (inside dimensions, 6x6x40 in.) and is readily removable.

Silver Brazing

"Scaiflux 21" is a new silver alloy brazing flux offered by the Scaife Company, Oakmont, Pa., having unusually low surface tension. It was developed by Scaife through its Mellon Institute fellowship for its own armament brazing operations, and is now available to industry. It is said to cut costs, simplify brazing and is adapted for brazing any type of ferrous or non-ferrous alloy. Available in both paste and dry form. (Continued on page 966)



Millions of

POWDERED METAL PARTS

NOW ACCURATELY PRODUCED ON THE NEW

KUX

POWDERED METAL PRESSES

MODEL 74

WRITE TO DEPT. MP for Catalog or Demonstration

COMPLETELY new patented design features now permit the manufacture of odd shapes of parts with complicated, cored holes, protruding lugs and various sectional thicknesses to micrometer accuracy. The formed pieces are made at speeds of up to 25 pieces a minute with uniform structural density throughout. Completely automatic in operation and applying up to 50 tons total pressure, Model No. 74 will produce parts up to 5" maximum diameter and has a powder cell, or die fill of 5½".

KUX MACHINE COMPANY
3924-44 W. HARRISON, ST. CHICAGO, ILL.

FLEXIBLE in Range . . . RIGID in Quality!

★ WILCO THERMOMETALS (thermostatic bimetals) have the *flexibility* to meet any temperature control or electrical resistance requirement—and the *quality* to maintain a tradition of excellence, which has continued unbroken for more than a quarter of a century.

★ Now functioning separately, now operating in conjunction with WILCO Electrical Contacts, WILCO THERMOMETALS are helping America win the war of the air, the sea and the land—helping through their matchless performance in Oil Temperature control, compensation in voltage regulators, and dependable action in many precision instruments.

★ Moreover, WILCO Aeralloy Electrical Contact Points are setting HIGH standards of service in aircraft MAGNETOS. Other WILCO Electrical Contacts are in tank, gun and ship applications—other WILCO THERMOMETALS in various instruments for the Army and Navy.

★ A SINGLE SOURCE OF SUPPLY. WILCO facilities permit manufacturing customers to secure both electrical contacts and thermostatic bimetal from a single source. This is important, for materials from these two groups are frequently used in conjunction, as parts in the same device. The most effective use of one necessitates a knowledge of the other. WILCO sales and engineering representatives are familiar with both Electrical Contact and THERMOMETAL application. Send us your problems for analysis.

WILCO PRODUCTS ARE: *Contacts*—Silver, Platinum, Tungsten, Alloys, Powder Metal. *Thermostatic Metal*—High and Low Temperature with Electrical Resistance from 24 to 530 ohms per sq. mil,-ft. *Precious Metal Collector Rings*—For rotating controls. *Jacketed Wire*—Silver on Steel, Copper, Invar, or other combinations requested.

THE H. A. WILSON COMPANY
105 Chestnut St., Newark, N. J.
Branches: Chicago ★ Detroit

WILCO

New Products

(Continued from page 964)

Improved Chilling Machine

New, improved "Deepfreeze Cascade" industrial chilling machine with many new features and refinements has widespread uses for shrinking, treating, and testing of metals. Machine has been designed with extra chilling capacity for high production of any part where large quantities of heat must be removed rapidly.

Features include a temperature controlling device for accurate temperature control at any point from atmosphere to —120° F.; a table top for convenience and safety; and a new system of three compressors and three motors which develops maximum thermal efficiency and eliminates necessity for water connections and drains.

One important application of this machine is the shrinking of metal at —100 to —120° F. to permit assembly of sleeve bearings and ball or roller races otherwise requiring a press-fit. After chilling the larger part, it is merely slipped into position. Another equally important use is the treatment of steel to produce uniform hardness and stress relief. Further information may be had from the Deepfreeze Div., Motor Products Corp., 2301 Davis St., North Chicago, Ill.

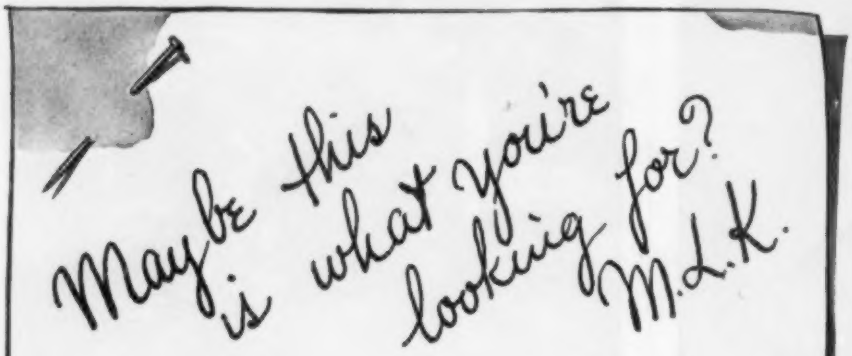
Dust Collector

Dust collector for use by processors of magnesium is announced by Industrial Equipment Corp., Detroit. Units are either of the booth type or individual collectors for grinding stands. Dust-laden air is drawn through an orifice meeting a violent spray

of water, where the dust is water-whirled out of the air and knocked down into a sludge tank below.

Air-Operated Controller

New air-operated automatic control instrument, known as Convertible Free-Vane Controller, has just been announced by the Bristol Co., Waterbury, Conn. New instrument is made for automatically controlling temperature (up to 3600° F.) flow, liquid level, pressure, draft humidity, pH value, and time program.



KEMP of BALTIMORE can provide, on high priority orders, industrial immersion heating (with gas) for soft metal casting and for lead and salt bath hardening and annealing. Exclusive Kemp gas-air premixing guarantees high speed production, fuel saving, automatic, accurate temperature control. For details address The C. M. Kemp Mfg. Co., 405 East Oliver Street, Baltimore, Md.

MAHR

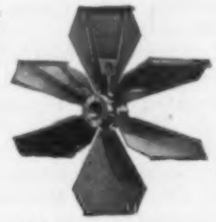
ENGINEERS • DESIGNERS • MANUFACTURERS
ALL EQUIPMENT FOR METAL HEATING

TEMPERATURE FANS

Designed for MAHR-built Furnaces . . . Now Available for All!

Do you have fan trouble? Do rotors burn out at high temperatures? Do you have excessive service and replacement costs? Here's a fan that will give you quick and permanent relief. Designed by our own engineers as standard equipment on MAHR Furnaces and Ovens — designed for temperature work specifically — thoroughly tested and proven—now offered to you as the most modern and satisfactory fan available today.

A ROTOR THAT WON'T BURN UP



This MAHR-designed 6-blade rotor just refuses to quit—no condition we have yet found up to 1500° F. disturbs it a particle.

LOOK AT THESE FEATURES!

- A FAN EASILY RE-ASSEMBLED FOR 16 STANDARD DISCHARGE POSITIONS. Any one of 8 c.w. and 8 c.c.w. positions can be easily and quickly obtained without cutting, welding or rebuilding. That's real flexibility.
- ACCESSIBILITY THAT SAVES PRECIOUS TIME —Note picture in panel showing how—by loosening a few bolts—the rotor, shaft, bearings and mounting can be pulled out as a unit for inspection or servicing.
- BEARINGS THAT CAN REALLY TAKE IT—All MAHR High Temperature Fans (800° to 1500° F.) have the latest self-aligning, ring-oiled, water-cooled, precision type sleeve bearings. Auxiliary cooling device helps dissipate heat load on the bearings.
- RATED OUTPUT DELIVERED AT RELATIVELY LOW SPEEDS—This reduces bearing wear, minimizes stresses and strains, prolongs life of fan.
- 10 SIZES—800 TO 40,000 C.F.M.—It's impossible here to tell all the important features of MAHR Temperature Fans—but they have fully satisfied our own exacting requirements and our bulletin will give the facts.

Ask for BULLETIN 1070 on MAHR Temperature Fans

If you do low temperature work under 800° F. or high temperature work 800° to 1500° F., you will benefit by investigating MAHR Fans for replacements or initial installations.

SALES REPRESENTATIVES IN PRINCIPAL CITIES

Any MAHR Sales Engineer will be glad to give you full information about MAHR Temperature Fans or any other MAHR products. Tell him your problems or write us.

THERE'S A MAHR FURNACE For EVERY HEAT TREATING NEED

	Furnace Types:	*Other MAHR Equipment:*
Annealing	Car Bottom	Rivet Forges
Carburizing	Pit	Torches
Baking	Pusher	Burners
Hardening	Roller Hearth	Blowers
Forging	Continuous	Valves
Drawing	Pot	Smithing Forges
Stress Relief	Rotary	

MAHR MANUFACTURING CO.

DIVISION OF DIAMOND IRON WORKS, INC.

1700 North Second Street **Minneapolis, Minnesota, U. S. A.**

WHAT'S NEW

IN MANUFACTURERS' LITERATURE

METAL WORKING • FABRICATION

Powdered metal presses producing millions of metal parts illustrated in catalog by Kux Machine Co. Bulletin Eg-500.

Rubberized fabric industrial gloves resistant to oil, grease and petroleum solvents as well as acids are described in leaflet by Edmont Mfg. Co. Bulletin Eg-506.

Forging presses. Ajax Mfg. Co. Bulletin Ff-105.

Horizontal extrusion presses. Hydropress, Inc. Bulletin Ff-394.

36-page pictorial story of the Cecostamp. Chambersburg Engineering Co. Bulletin Ff-132.

Cutting Oils. Cities Service Oil Co. Bulletin Ec-113.

Cutting Oil Handbook. D. A. Stuart Oil Co. Bulletin Ke-118.

Presses for Powder Metallurgy. F. J. Stokes Machine Co. Bulletin Af-335.

Properties and uses of cutting oils. Gulf Oil Corp. Bulletin Ef-360.

Illustrated data information on cutting oils and their correct use in machining operations. National Refining Co. Bulletin Cg-479.

"Dag" colloidal graphite as a high temperature lubricant is described by Acheson Colloids Corp. Bulletin Fg-465.

Information and data on new straightening press is offered by Anderson Bros. Mfg. Co. Bulletin Dg-491.

Forty different ways to cut machining costs. Continental Machines, Inc. Bulletin Ef-170.

Mounted wheels, Handee and Hi-Power tools. Chicago Wheel & Mfg. Co. Bulletin Kf-230.

Properties, applications and use of hard-facing rods are described by Coast Metals, Inc. Bulletin Fg-361.

Surface coated abrasive belts. Minnesota Mining & Mfg. Co. Bulletin Ag-470.

Grinding and polishing with abrasive belts. Hammond Machinery Builders, Inc. Bulletin Cg-363.

Handbook on aircraft riveting operations. Cherry Rivet Company. Bulletin Dg-486.

Stampings with new Hi-Speed press. Di Machine Corp. Bulletin Dg-490.

Savings in oils, tool bits, grinding wheels. Sparkler Mfg. Co. Bulletin Kf-433.

"Hyper-milling", a radical innovation in face-milling of steel. Firth-Sterling Steel Co. Bulletin Lf-177.

Big, comprehensive data book describes specialized oils and shows uses for hydraulic oils in metal working. Warren Refining & Chemical Co. Bulletin Eg-454.

265-page textbook covers techniques used in contour machining, laboratory controls in manufacture of precision saw bands. Doall Service Co. Bulletin Eg-297.

Precision grinding wheel. American Emery Wheel Works. Bulletin Eg-501.

Brazing of cemented carbide tools. Carboloy Co. Bulletin Eg-278.

Cutting Fluids. Pate Oil Co. Bulletin Eg-496.

Presses for the metal working and process industries. Hydraulic Press Mfg. Co. Bulletin Eg-475.

Multi-wash dust collectors for aluminum-magnesium metal working plants. Claude B. Schneible Co. Bulletin Eg-161.

New catalog illustrates standard, non-standard, and special tools, shows prices of tools and blanks. McKenna Metals Co. Bulletin Fg-238.

Abrasive belt polishing machines. Divine Brothers Co. Bulletin Kf-434.

Abrasive cloth gadgets. Behr-Manning Corp. Bulletin Nf-467.

Advantages and physical characteristics of "No-Wear", a hard-facing material, are described in new bulletin by Callite Tungsten Corp. Bulletin Fg-327.

FERROUS METALS

New war time edition of the machinery steel selector has just been issued by the Elastuf group which includes Horace T. Potts, Brown Wales and Beals, McCarthy & Rogers. Bulletin Fg-264.

Aircraft steels, bearing steels. Rotary Electric Steel Co. Bulletin Kf-429.

Steels. Boker & Co. Bulletin Kf-450.

Steel Data Sheets. Wheelock, Lovejoy & Co. Bulletin Ox-74.

Molybdenum wrought steels. Molybdenum Corp. of America. Bulletin Nf-312.

Use Handy Coupon Below for Ordering Helpful Literature.

Other Manufacturers' Literature Listed on Pages 972, 974, 976, 978, 980, 982, 984, 986 and 988.

Metal Progress 7301 Euclid Ave., Cleveland
Send me the literature I have indicated below.

Name .... **Title** ....

Company .... **Address** ....

(Students—please write direct to manufacturers.)
Check or circle the numbers referring to literature described on these 10 pages.

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Eg-500	Ef-170	Eg-278
Eg-506	Kf-230	Eg-496
Ff-105	Ff-361	Eg-475
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Ff-132	Cg-363	Fg-238
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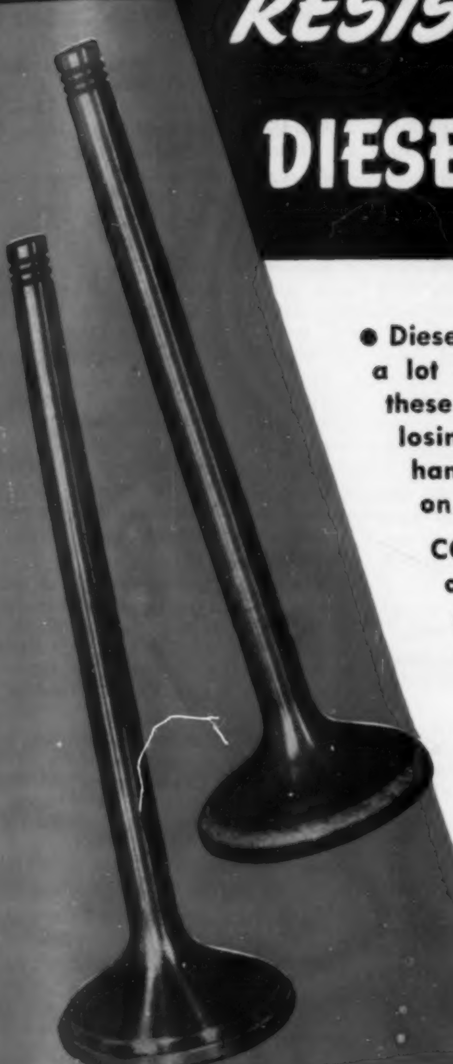
COLMONOY No. 4

HARD FACING ALLOY

RESISTS SEVERE WEAR IN DIESEL ENGINE VALVES



- Diesel engine valves, in locomotive service, must take a lot of punishment. Roadbed cinders and dust caused these valves to fail in service, wearing down rapidly and losing compression. To salvage the valves already on hand an undercut was made as shown in the illustration on the left.

COLMONOY No. 4 was applied in the undercut by oxy-acetylene welding, and subsequently machined and ground. Due to the low temperature at which the application was made there was absolutely no distortion in the valves.

Service records show that the great abrasion resistance of COLMONOY completely solved the problem of wear.

There is a grade of COLMONOY for every hard facing need. If you have a wear problem, COLMONOY engineers will be glad to make recommendations and suggest proper methods of application.

WALL-COLMONOY CORP.
720 Fisher Building, Detroit
Branch offices in New York City, Blasdell, N. Y., Chicago, Tulsa, Los Angeles and in Canada.

COLMONOY
HARD FACING ALLOYS AND OVERLAY METALS

WALL-COLMONOY CORPORATION—DETROIT

WHAT'S NEW

IN MANUFACTURERS' LITERATURE

New corrosion data work sheet acts as check list to insure consideration and evaluation of all factors influencing corrosive action. International Nickel Co. Bulletin Eg-45.

Enduro stainless steels. Republic Steel Corp. Bulletin Hf-8a.

Hard Facing Alloys. Wall-Colmonoy Corp. Bulletin Kd-85.

Free Machining Steels. Monarch Steel Co. Bulletin Cd-255.

Tool Steels. Bethlehem Steel Co. Bulletin Ce-76.

Die Steels. Latrobe Electric Steel Co. Bulletin Ld-208.

Enameling iron sheets. Inland Steel Co. Bulletin Ld-295.

NAX high tensile low alloy steels. Great Lakes Steel Corp. Bulletin Kd-229.

Loose-leaf reference book on molybdenum steels. Climax Molybdenum Co. Bulletin Hb-4.

Four Coppco tool steels. Copperweld Steel Co. Bulletin Cf-311.

Stainless steel. Allegheny Ludlum Steel Corp. Bulletin Df-92.

New process embodying both chemical and temperature controls for production of low carbon open hearth case carburizing steel is described in bulletin by W. J. Holliday & Co. Bulletin Bg-293.

Shop notes on the machining of stainless steels. Rustless Iron & Steel Corp. Bulletin Nf-169.

Aircraft Alloy Steels. Joseph T. Ryerson & Son, Inc. Bulletin Eg-106.

NON-FERROUS METALS

Reynolds Metals Co. has issued two color charts showing marking for identification of wrought aluminum alloy products, rod, bar, tubing and shapes, and for aluminum alloy sheet. Bulletin Fg-436.

Heat treatment of aluminum bronzes is one of the articles in leaflet issued by H. Kramer & Co. Bulletin Fg-508.

Platinum Metal Catalysts. Baker & Co., Inc. Bulletin Af-337.

Die casting equipment. Lester-Phoenix, Inc. Bulletin Kf-437.

Handy & Harman has issued a revised edition of their general catalog on Sil-Fos and Easy-Flo brazing alloys. Bulletin Eg-126.

Bronze. Frontier Bronze Corp. Bulletin Kf-455.

Copper Alloys. American Brass Co. Bulletin Kd-89.

Aluminum Castings. National Bronze & Aluminum Foundry Co. Bulletin De-307.

Cerrosafe, a low temperature melting metal, used to accurately proofcast cavities. Cerro de Pasco Copper Corp. Bulletin Kf-421.

Brass and bronze castings. Hammond Brass Works. Bulletin Df-371.

Reference on properties of lead. St. Joseph Lead Co. Bulletin If-415.

6th edition of Revere Weights and Data Handbook. Revere Copper and Brass, Inc. Bulletin Bg-239.

Catalog of brass, bronze and iron alloys. Cramp Brass and Iron Foundries Div., Baldwin Locomotive Works. Bulletin Gf-67.

Dowmetal data book. Dow Chemical Co. Bulletin Ec-215.

80-page Duronze Manual, well indexed for reference, presents data on high strength silicon bronzes. Bridgeport Brass Co. Bulletin Nf-163.

Forgeable tin-free bearing metal. Mueller Brass Co. Bulletin Cg-481.

Surface protection for magnesium. American Magnesium Corp. Bulletin Cg-482.

Standard specifications for all grades of aluminum alloys (casting grades only). Federated Metals Div., American Smelting and Refining Co. Bulletin Cg-478.

Rare metals, alloys and ores. Foote Mineral Co. Bulletin Cg-483.

Everyone joining nonferrous metals needs the new 12-page Westinghouse Brazing Booklet, crammed with timely ideas for saving man-hours and critical materials. Westinghouse Elec. & Mfg. Co. Bulletin Dg-134.

WELDING

"Sureweld" protected arc electrodes. Hollup Corp., division of National Cylinder Gas Co. Bulletin Ag-331.

Welding Stainless. Page Steel & Wire Div., American Chain & Cable Co., Inc. Bulletin Ne-86.

Chart explains how to select proper flux for every welding, brazing and soldering job. Krembs & Co. Bulletin Ff-393.

Electrode quantity and welding time graph. Arcos Corp. Bulletin Ld-191.

Oxy-acetylene welding and cutting. Linde Air Products Co. Bulletin Ge-63.

Arc welding accessories available through General Electric Co. are illustrated in new Bulletin Lf-60.

Sciaky radial portable welder. Sciaky Brothers. Bulletin Kf-425.

Two-stage "Regolator" for producing a non-fluctuating welding flame. National Cylinder Gas Co. Bulletin Af-331.

Speed is increased 20 to 30% and power costs cut one-third with the Flexarc A-C welders described in new booklet by Westinghouse Electric & Mfg. Co. Bulletin Ag-134.

Data book facts on spot, seam and flash welding ferrous and non-ferrous metals and alloys. P. R. Mallory & Co., Inc. Bulletin Cg-220.

Welding and brazing of aluminum, a new data book issued by Aluminum Co. of America. Bulletin Cg-54.

Shield Arc electrodes. McKay Co. Bulletin Gf-248.

Silver Red electrodes for cutting tools and Silver Green electrodes for chisel steels are described in data sheets just added to the catalog of arc welding equipment issued by American Agile Corp. Bulletin Dg-485.

Modern goal in equipment design and welding technique is outlined in bulletin "New Advances in Arc Welding Equipment Design" by Harnischfeger Corp. Bulletin Dg-171.

Use Handy Coupon on Page 970 for Ordering Helpful Literature.
Other Manufacturers' Literature Listed on Pages 970, 974, 976, 978, 980, 982, 984, 986 and 988.

Eliminate NEEDLESS HEAT

IN YOUR HEAT TREAT DEPARTMENT THIS SUMMER

NON BURNING

CHAR CARBURIZERS

WILL NOT BURN EVEN WHEN DISCHARGED DIRECTLY INTO THE AIR

IN DIRECT QUENCH OR ROTARY PRACTISE

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CHAR PRODUCTS COMPANY

MERCHANTS BANK BUILDING INDIANAPOLIS

THE DIAMOND BLOCK METHOD FOR HARDENING HIGH SPEED

without { SCALE, CARBURIZATION OR DECARBURIZATION

A correct atmosphere, which is absolutely constant and requires no regulation or adjustment, is generated by the Diamond Block. There is no variation from "heat to heat" or "day to day", and a uniformly fine product is assured.

Tools retain their initial clean-cut edges and have maximum hardness and excellent grain structure.

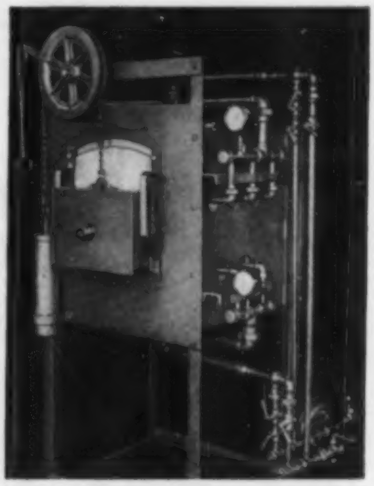
Many sizes of work can be done in three different furnaces from a bench type to a real production job.

Write us today.

AMERICAN GAS FURNACE CO.

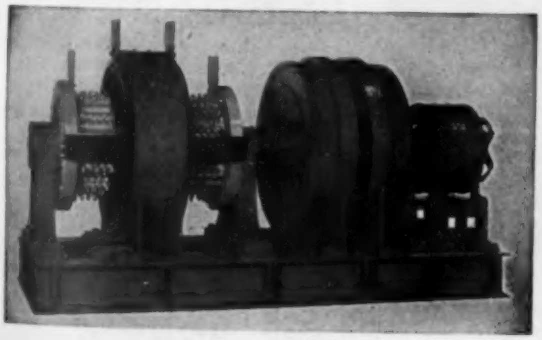
ELIZABETH, N. J.

AMERICAN GAS FURNACE CO. 1878



COLUMBIA MOTOR-GENERATORS

for Electro-Plating and other Electrolytic Processes



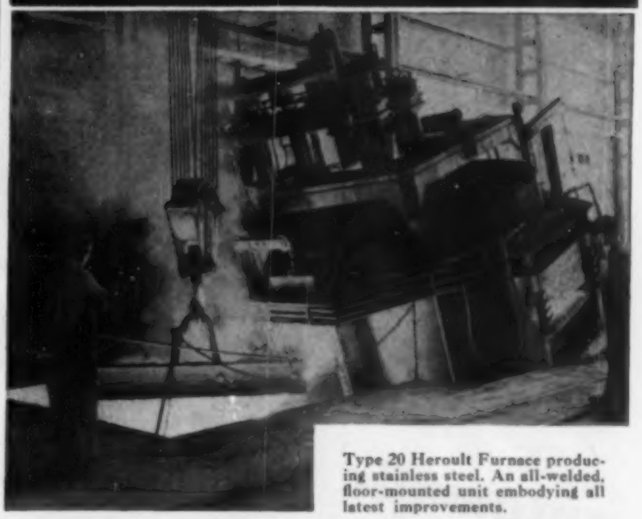
Columbia generators embody every feature essential to dependable, 24-hour operation. They are built for electroplating service in sizes of 6 to 20 volts, 500 to 20,000 amperes; for anodic treatment of aluminum in sizes of 40, 50 and 60 volts, 500 to 3,000 amperes. Columbia generators for other electrolytic processes range from ½ to 250 KW, 100 to 40,000 amperes, 6 to 60 volts.

Prompt shipment can be made on any type and size. What are your requirements?

COLUMBIA ELECTRIC MFG. CO.

4519 Hamilton Ave. Cleveland, Ohio

Heroult ELECTRIC FURNACES



Type 20 Heroult Furnace producing stainless steel. An all-welded, floor-mounted unit embodying all latest improvements.

PARTICULARLY designed and equipped for high-quality melting and refining of ferrous materials by either basic or acid process—including alloy, tool and forging steels, iron and steel castings. Any capacity from ½ ton to 100 tons; removable roof, chute, machine or hand charging.

AMERICAN BRIDGE COMPANY

General Offices: Pittsburgh, Pa.
Offices in the larger cities

USS Columbia Steel Company, San Francisco, *Pacific Coast Distributors*
United States Steel Export Company, New York

UNITED STATES STEEL

WHAT'S NEW

IN MANUFACTURERS' LITERATURE

New color chart shows correct oxyacetylene flame adjustment. Air Reduction Co. Bulletin Eg-69.

Precision welder. Hercules Electric & Mfg. Co., Inc. Bulletin Nf-470.

Improved method for welding cast iron is described by Eutectic Welding Alloys Co. Bulletin Fg-301.

Nu-Braze No. 4, an improved silver brazing alloy for use with ferrous and nonferrous metals is described by Sherman & Co. Bulletin Fg-514.

TESTING & CONTROL

SR-4 strain gage and illustrations of its many uses. Baldwin Southwark. Bulletin Eg-67.

Clinometer, a new, pendulum-type angle gage adapted for inspection room use, described in new leaflet by Engis Equipment Co. Bulletin Fg-507.

Just out is Westinghouse's new book containing a wealth of practical, usable information on industrial inspection by x-ray. Westinghouse Electric & Mfg. Co. Bulletin Eg-134.

New fixtures and accessories to extend usefulness of X-ray quartz analysis apparatus are described by Philips Metalix Corp. Bulletin Fg-471.

New illustrated booklet describes time-saving metallurgical polishing equipment by Tracy C. Jarrett. Bulletin Fg-303.

New Picker X-Ray accessory and supply catalog illustrates many accessories employed in industrial radiography. Bulletin Eg-348.

Radiographic identification of negatives with lead markers is described in leaflet by H. W. Knight & Son, Inc. Bulletin Eg-503.

Electric heaters and controls for industrial and laboratory. American Instrument Co. Bulletin Eg-259.

12-page catalog describes electric motor valve operators as applied to standard temperature control systems for fuel-fired furnaces. Automatic Temperature Control Co. Bulletin Fg-384.

Carbon-Meter for rapidly determining carbon at the furnace is described in booklet by E. Leitz, Inc. Bulletin Fg-47.

Wheelco Instruments Co. has just issued five new bulletins describing its complete line of industrial indicating, recording and control thermometers. Bulletin Bg-110.

8-page bulletin describes line of new convertible free-vane air-operated controllers. Bristol Co. Bulletin Fg-87.

New 29-page catalog — Micromax Electric Control — has just been issued by Leeds & Northrup Co. Bulletin Bg-46.

"Kodak Products for Industrial Radiography". Eastman Kodak Co. Bulletin Ff-395.

Inspection of non-magnetic metals with the new Zyglo method. Magnaflux Corp. Bulletin If-401.

Industrial radiography with radium. Canadian Radium & Uranium Corp. Bulletin Ff-320.

X-Ray Diffraction Unit. General Electric X-ray Corp. Bulletin He-6.

Radium for industrial radiography. Radium Chemical Co., Inc. Bulletin Bf-345.

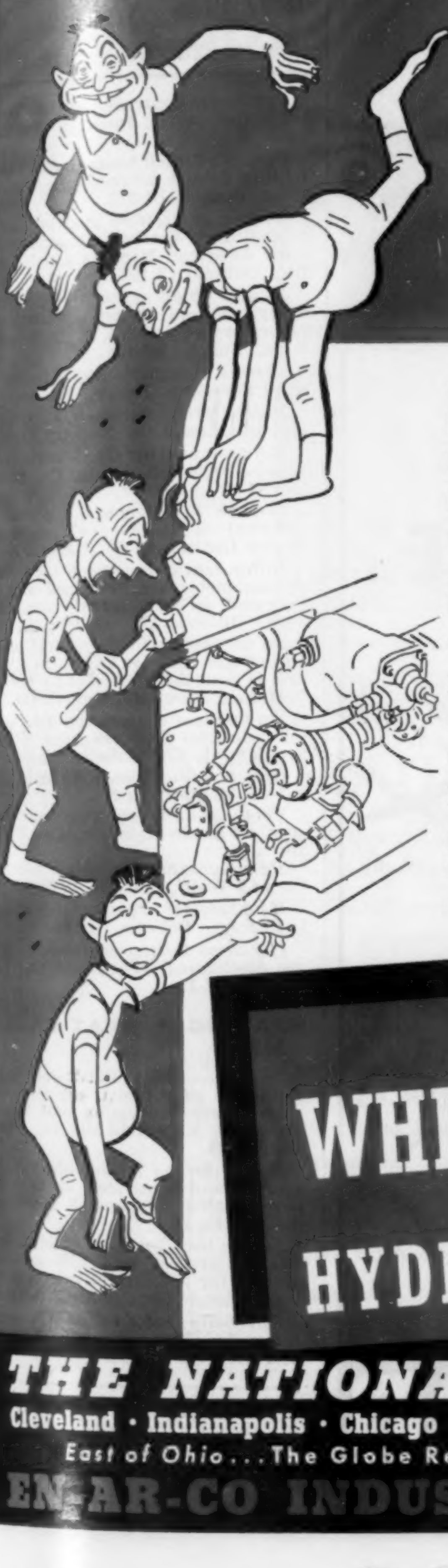
Film and plate processing equipment for spectro analysis. Harry W. Dietert Co. Bulletin Af-198.

Potentiometer temperature indicators. Foxboro Co. Bulletin Ef-21.

Gage blocks, comparators, projectors. George Scherr Co. Bulletin Kf-206.

Use Handy Coupon on Page 970 for Ordering Helpful Literature.

Other Manufacturers' Literature Listed on Pages 970, 972, 976, 978, 980, 982, 984, 986 and 988.



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WHAT'S NEW

IN MANUFACTURERS' LITERATURE

Pyrometer Controller. Illinois Testing Laboratories, Inc. Bulletin Hb-180.

Portable Brinell hardness tester and folding Brinell microscope. Andrew King. Bulletin Df-377.

Universal testing machines and typical uses. Riehle Testing Machine Div., American Machine and Metals, Inc. Bulletin Cf-157.

Slomin high speed electrolytic analyzers and other metallurgical laboratory equipment. E. H. Sargent & Co. Bulletin Kf-458.

Surface Analyzer. Brush Development Company. Bulletin Kd-288.

Micro-Optical Pyrometers. Pyrometer Instrument Co. Bulletin Kc-37.

X-Ray metallurgical laboratory service. Claud S. Gordon Co. Bulletin Nf-53.

64-page booklet on the precision control of industrial processes. Brown Instrument Co. Bulletin Nf-3.

Dillon tensile tester and the Dillon dynamometer are described and illustrated in new leaflet issued by W. C. Dillon & Co. Bulletin Ag-466.

An innovation in the manual methods of gas analysis known as Catalysis is described in leaflet by Burrell Technical Supply Co. Bulletin Dg-213.

Catalog and engineering data book on industrial thermocouples. Arklay S. Richards Co. Bulletin Dg-330.

Optical Aids. Bausch & Lomb Optical Co. Bulletin Ce-35.

Coleman universal spectrophotometer. Wilkens-Anderson Co. Bulletin Lf-7.

Metallographic polishing powder. Conrad Wolff. Bulletin Cf-368.

Metallurgical Equipment. Adolph I. Buehler. Bulletin Ke-135.

Hardness testing equipment. Wilson Mechanical Instrument Co., Inc. Bulletin Cf-22.

HEATING • HEAT TREATMENT

36-page catalog illustrates Kold-Hold line of thermal, sub-zero and stratosphere processing and testing machines. Kold-Hold Mfg. Co. Bulletin Eg-399.

Homo method for nitriding is described and illustrated in new 19-page catalog by Leeds & Northrup. Bulletin Eg-46.

Lithco, the chemically-neutral heat treating process, and Lithcarb, the process for fast, bright gas-carburizing. Lithium Corp. Bulletin Ef-319.

Internally heated salt bath furnaces and pots. Upton Electric Furnace Div. Bulletin Ef-386.

Use Handy Coupon on Page 970 for Ordering Helpful Literature. Other Manufacturers' Literature Listed on Pages 970, 972, 974, 978, 980, 982, 984, 986 and 988.

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WHAT'S NEW

IN MANUFACTURERS' LITERATURE

Induction heating. Induction Heating Corp. Bulletin Ef-323.

S.F.E. Standard Industrial furnace catalog. Standard Fuel Engineering Co. Bulletin Kf-388.

Easy-selection charts on gas-burning equipment. National Machine Works. Bulletin Ag-310.

Electric Furnaces. Ajax Electrothermic Corp. Bulletin He-41.

8-page pictorial bulletin describes the heat treating service of Continental Industrial Engineers, Inc. Bulletin Nf-154.

Hagan rotary forging furnaces are described in bulletin by George J. Hagan Co. Bulletin Cg-476.

Comprehensive, 100-page textbook describes constructional features, capacities, operation and instrumentation of nitriding furnaces. Nitralloy Corp. Bulletin Fg-116.

Profusely illustrated booklet shows many applications of Lindberg furnaces for accurate heat treatment of aluminum, magnesium and their alloys. Lindberg Engineering Co. Bulletin Fg-66.

New 20-page booklet describes centrifugal blowers and exhausters. Roots Connersville Blower Corp. Bulletin Fg-131.

Continuous type gas carburizin[g] furnaces are described by Surfac[e] Combustion. Bulletin Fg-51.

Heavy duty high temperature all[oy] steel fans are described by Despatc[h] Oven Co. Bulletin Fg-123.

48 illustrated pages describe Pre[cision]-Freas constant temperature control cabinets. Prescision Scien[tific] Co. Bulletin Fg-510.

"The Trend Is Toward Salt" i[s] title of interesting leaflet showin[g] several examples of heat treatment Ajax Electric Co. Bulletin Fg-43.

Unusual accessibility and othe[r] features of new high temperature fans are described in new leaflet b[y] Mahr Mfg. Bulletin Fg-5.

Gas, oil and electric heat treatin[g] and carburizing furnaces. Holcrof[t] & Co. Bulletin Lf-203.

Rotary Hearth Furnaces. Lee Wi[l]son Sales Corp. Bulletin Ce-302.

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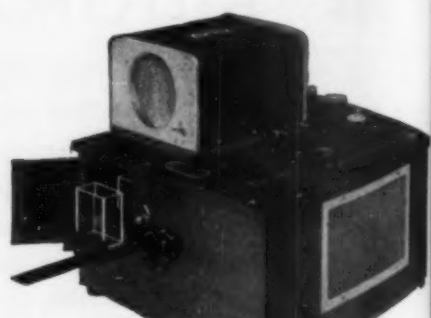

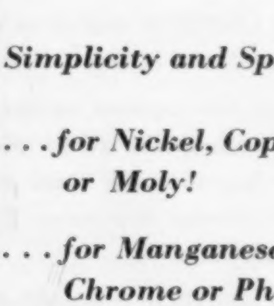

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WHAT'S NEW

IN MANUFACTURERS' LITERATURE

Industrial furnaces, equipment for bright annealing stainless steels and ammonia dissociation equipment. Drever Co. Bulletin Ff-321.

Industrial ovens, rod bakers, welding rod ovens, furnaces. Carl-Mayer Corp. Bulletin Bf-183.

Full muffle and other heat treating furnaces described in catalog by Charles A. Hones, Inc. Bulletin Eg-445.

56-page vest pocket data book on heat treating practices and procedures. Chicago Flexible Shaft Co. Bulletin Hf-49.

Non-metallic Electric Heating Elements. Globar Div., Carborundum Co. Bulletin Lb-25.

24-page catalog describes gas, oil and electric Holden heat treating pot furnaces, and baths. A. F. Holden Co. Bulletin Lf-55.

Modern electric furnaces for heat treating. Harold E. Trent Co. in new Bulletin Lf-461.

Control of temperatures of quenching baths. Niagara Blower Co. Bulletin Cf-367.

Molten Salt Baths. E. I. DuPont de Nemours & Co., Inc., Electrochemicals Department. Bulletin If-413.

Faster production with Tocco hardening, brazing, annealing and heating machines. 16-page booklet by Ohio Crankshaft Co. Bulletin Lf-145.

Kleen-well oil strainers for quench oil cooling systems. Bell & Gossett Co. Bulletin Lf-287.

Gas cracking unit for production of a protective atmosphere during heat treatment of alloy and high carbon tool steels. Hevi-Duty Electric Co. in new Bulletin Lf-44.

Unichrome alkaline copper processes for improvement of selective hardening and deep drawing of steel. United Chromium, Inc. Bulletin Lf-463.

Handling cylinder anhydrous ammonia for metal treaters. Armour Ammonia Works. Bulletin Lf-443.

"Pulverized Coal, the Victory Fuel". Amsler-Morton Co. Bulletin Ff-286.

Heat treating furnaces. Johnston Mfg. Co. Bulletin Ff-155.

Drycolene. General Electric fur-nace atmosphere. Bulletin Df-60.

Dual-Action quenching oil. Gu Oil Co. Bulletin Df-360.

Electric box type and muffle fur-naces. H. O. Swoboda, Inc. Bulleti Ef-379.

Industrial Furnaces. W. S. Rock well Co. Bulletin Kc-34.

Certain Curtain Furnaces. C. I Hayes, Inc. Bulletin Nc-15.

Air-Oil Ratiotrol for proportionin flow of fuel oil and air to oil burner is described in new bulletin by th North American Mfg. Co. Bulleti Dg-138.

Blue Print for Industry is title o new handbook presenting oven engi neering information on 28 installa tions with description of design an process. Industrial Oven Engineer ing Co. Bulletin Dg-494.

Interesting and helpful informa tion available on the use of alloy pots for heating operation by the Swedish Crucible Steel Co. Bulleti Cg-484.

Gas-air premix machine. Eclip Fuel Engineering Co. Bulletin Cg-22

Two new bulletins on vertical car burizers and on carbonia finish American Gas Furnace Co. Bulle tin Cg-11.

Low temperature equipment fo aging, shrinking, etc. Deepfree Div., Motor Products Corp. Bulleti Kf-444.

Heat treating furnaces. McCann Furnace Co. Bulletin Kf-446.

Controlled atmosphere furnace fo heat treatment of tool and alloy steels. Delaware Tool Steel Corp. Bulletin Kf-439.

Furnaces. Tate-Jones Co. Bulleti Kf-447.

Industrial Carburetors. C. M Kemp Mfg. Co. Bulletin Ce-219.

New Van Norman induction heat-ing units are comprehensively de-scribed and typical operations pic-tured in attractive 8-page folder by Van Norman Machine Tool Co. Bulletin Dg-487.

New 8-page, well-illustrated cata-log describes equipment for flame-hardening, flame-annealing, mecha-nized-brazing, preheating and other localized open heat treatments by the Selas Co. Bulletin Dg-214.

High and low temperature direct fired furnaces as well as convection types for stress relieving and draw-ing are described in new 8-page leaf-let by R-S Products Corp. Bulletin Dg-234.

Hy-Speed Case for increasing the life of high speed tools. A. F. Holden Co. Bulletin Dg-55.

Heat treating, brazing and melt-ing of ferrous and non-ferrous metals. Lepel High Frequecy Laboratories, Inc. Bulletin Kc-211.

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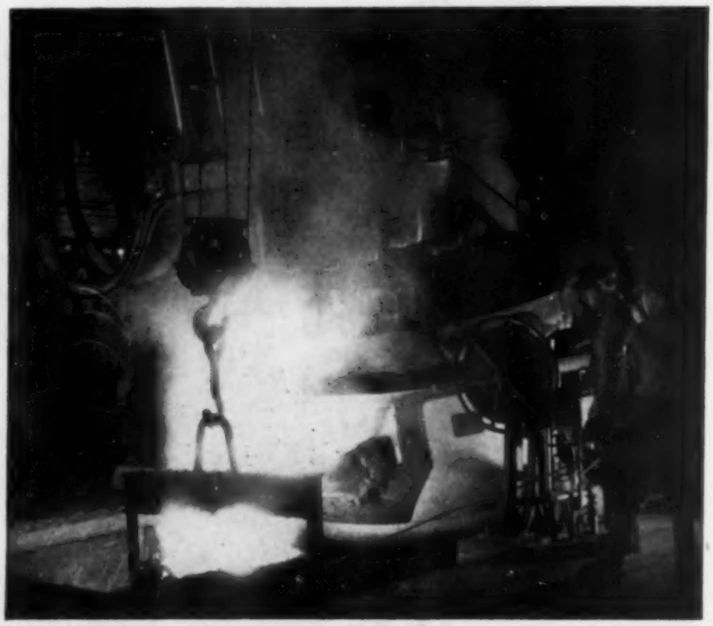

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WHAT'S NEW

IN MANUFACTURERS' LITERATURE

Vertical Furnace. Sentry Co. Bulletin Ne-114.

Conveyor Furnaces. Electric Furnace Co. Bulletin Be-30.

New Electric Furnace. American Electric Furnace Co. Bulletin Gd-2.

Newly developed salt bath material for use in Martempering process. E. F. Houghton & Co. Bulletin Dg-38.

Electric Furnaces for laboratory and production heat treatment. Hoskins Mfg. Co. Bulletin Cf-24.

Furnace Experience. Flinn & Dreffein Co. Bulletin Bc-82.

Flame-type mouth and taper annealing machine for steel cartridge cases. Morrison Engineering Corp. Bulletin Nf-305.

Dehumidifier. Pittsburgh Lectrodryer Corp. Bulletin Bb-187.

No-Carb, a liquid paint for prevention of carburization or decarburization. Park Chemical Co. Bulletin Nf-141.

Furnaces. Dempsey Industrial Furnace Corp. Bulletin Ke-260.

High Temperature Fans. Michiana Products Corp. Bulletin Hb-81.

Turbo-compressors. Spencer Turbine Co. Bulletin Cf-70.

16-page engineering and data booklet on proportioning oil burners. Hauck Mfg. Co. Bulletin Nf-181.

Pictorial bulletin describes furnaces for heat treating, normalizing, annealing, forging. Vulcan Corp. Bulletin Ag-448.

REFRACTORIES & INSULATION

Insulating firebrick. Babcock & Wilcox Co. Bulletin Ce-75.

D-E insulating materials and their application are described in new data booklet by Armstrong Cork Co. Bulletin Eg-221.

Cromox, a new protective refractory coating material for prolonging the life of firebrick, insulating firebrick, and castable refractories in coal, oil, gas-fired and electric furnaces, as well as in nonferrous melting furnaces. Federal Refractories Corp. Bulletin Eg-497.

Heavy Duty Refractories. Norton Co. Bulletin Ie-88.

Super Refractories catalog. Carborundum Co. Bulletin Ld-57.

P. B. Sillimanite refractories. Chas. Taylor Sons Co. Bulletin Ef-218.

Conductivity and heat transfer charts. Johns-Manville. Bulletin Df-100.

Ramix bottom for basic open hearth furnaces. Basic Refractories, Inc. Bulletin Nf-192.

Brickseal refractory coating. Brickseal Refractory Co. Bulletin Ag-40

Corhart Electrocast Refractories for the melting and refining of metals are described by Corhart Refractories Co. Bulletin Dg-493.

FINISHING, PLATING, CLEANING

Nielco Laboratories offers technical data sheet on brass and copper alkali cleaner. Bulletin Bg-472.

Well-rounded and helpful catalog on finishing and cleaning has been issued by Frederick Gumm Chemical Co., Inc. Bulletin Eg-505.

Fine illustrated folder describes Roto-Finish equipment and its use for de-burring, buffing, polishing and coloring. Sturgis Products Co. Bulletin Eg-504.

Resilon corrosion-resistant tank linings and applications are described in 8-page leaflet by United States Stoneware Co. Bulletin Ff-356.

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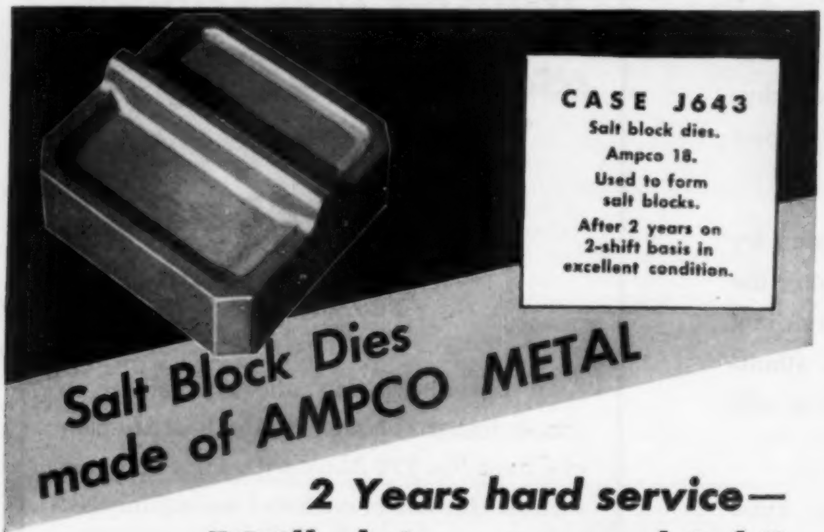

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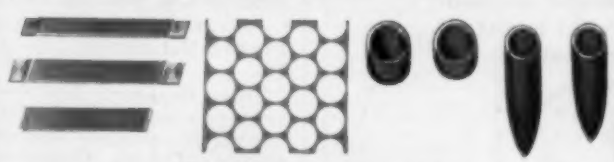

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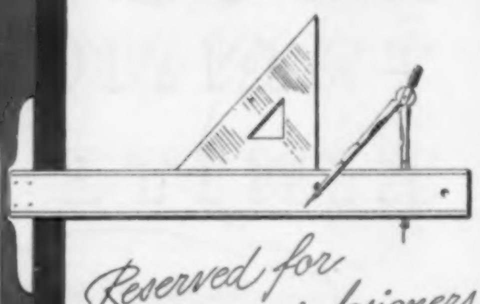

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WHAT'S NEW

IN MANUFACTURERS' LITERATURE

A protective, deep black finish to steel. Heatbath Corp. Bulletin Hf-189.

Alvey Ferguson Co. shows how various product washing problems were solved. Bulletin Ne-329.

Four new booklets describe blackening processes for metals, for aluminum, zinc and copper. Enthone Co. Bulletin Fg-240.

Motor-Generators for electroplating and other electrolytic processes. Columbia Electric Mfg. Co. Bulletin Bf-352.

Pickling. Wm. M. Parkin Co. Bulletin Ff-193.

Detrex metal cleaning machines, metal cleaning chemicals and processing equipment. Detroit Rex Products Co. Bulletin Lf-111.

Service report describes use of Oakite machining, drawing, degreasing and descaling materials to speed and simplify fabrication and surface treatment of stainless steels. Oakite Products, Inc. Bulletin Eg-296.

Airless Rotoblast. Pangborn Corp. Bulletin Hf-68.

Cadmium Plating. E. I. duPont deNemours & Co., Inc. Bulletin Hf-29.

Anodizing and plating equipment. Lasalco, Inc. Bulletin Kf-457.

Degreasers. Phillips Manufacturing Co. Bulletin Nc-254.

Electrochemical Descaling. Bullard-Dunn Process Div., Bullard Co. Bulletin Ge-143.

Jetal process and its characteristics as a protective coating. Alrose Chemical Co. Bulletin Gf-256.

Tumbling and cleaning. Globe Stamping and Machine Co. Bulletin Kf-456.

Rust inhibiting wax coatings for protection of metal. S. C. Johnson & Son, Inc. Bulletin Kf-426.

Rust Preventative. Alox Corp. Bulletin Nb-212.

Casting cleaning methods in foundries. N. Ransohoff, Inc. Bulletin Bf-381.

New industrial washing equipment is described by American Foundry Equipment Co. Bulletin Dg-112.

"Indium and Indium Plating". Indium Corp. of America. Bulletin Df-376.

MELTING • CASTING • MILL OPERATIONS

Care of crucibles for brass, copper, aluminum and magnesium industries. Electro Refractories and Alloys Corp. Bulletin Ff-396.

Melting, holding and alloying furnaces. Fisher Furnace Co. Bulletin Bg-195.

Manganese-Titanium Steels. Titanium Alloy Mfg. Co. Bulletin Ga-90.

Stroman crucible melting furnaces for aluminum and magnesium are described in leaflet by Stroman Furnace & Engineering Co. Bulletin Fg-509.

Operating Features, capacities, charging methods of the Heroult electric furnace. American Bridge Co. Bulletin Bf-124.

Ingot Production. Gathmann Engineering Co. Bulletin Ka-13.

"Electromet Products and Service". Electro Metallurgical Co. Bulletin Bf-16.

How Research Has Produced developments that make the side-blow converter process desirable as a source of high temperature metal. Whiting Corp. Bulletin Bf-357.

Chrom-X for steel mill and foundry. Chromium Mining & Smelting Co. Bulletin Kf-451.

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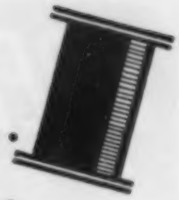

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Electric Furnaces. Detroit Electric Furnace Div., Kuhlman Electric Co. Bulletin Hd-271.

Chart for the correction of brasses for zinc loss should interest foundrymen. Foundry Services, Inc. Bulletin Dg-489.

Alloy additions to gray iron, malleable and semi-steel are discussed and newest information presented in booklet by Niagara Falls Smelting & Refining Corp. Bulletin Dg-467.

ENGINEERING • APPLICATIONS • PARTS

An engineer's handbook on electrical contacts. Fansteel Metallurgical Corp. Bulletin Eg-477.

Just released by Atlas Brass Foundry is an 84-page catalog listing sizes and prices of hundreds of finished bronze bushings and porous oil-retaining bearings. Bulletin Eg-502.

Finding list and list of sources of alloy metals. Hobart Brothers Co. Bulletin Eg-20.

Production of gray iron and semi-steel castings is described in an illustrated booklet issued by Forest City Foundries Co. Bulletin Eg-499.

Flanges and other drop forgings. Ladish Drop Forge Co. Bulletin Eg-441.

Chace manganese alloy No. 772 in sheets, strips, rod and special shapes described by W. M. Chace Co. Bulletin Eg-232.

Centrifugal castings. Shenango-Penn Mold Co. Bulletin Eg-174.

Electrical, corrosion and heat resisting alloys in rod, wire, ribbon and strip forms. Wilbur B. Driver Co. Bulletin Kf-430.

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12-page booklet presents a great deal of useful information on many specialties Summerill Tubing Co. is producing, including tapered and formed tubes and wide variety of special shapes. Bulletin Fg-108.

Extruded AMS 4640 bronze data sheet has been issued by Ampco Metal, Inc. Bulletin Fg-175.

Attractive booklet on Bunting cast bronze, sleeve type standardized bearings. Bunting Brass & Bronze Co. Bulletin Cg-473.

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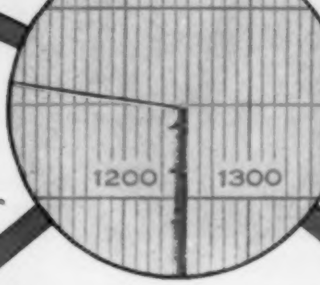

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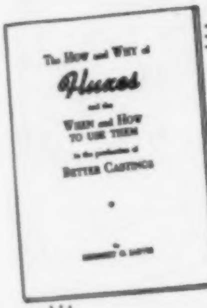

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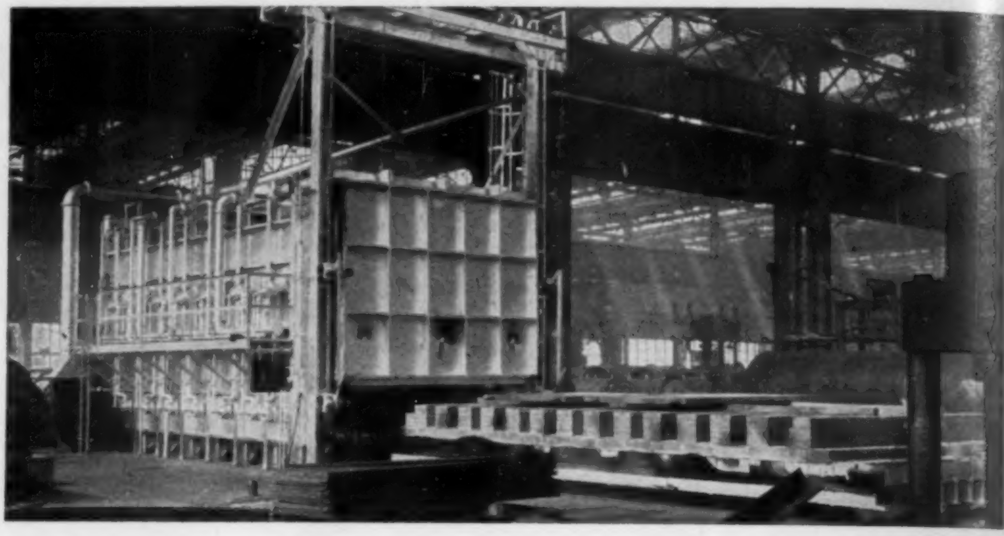

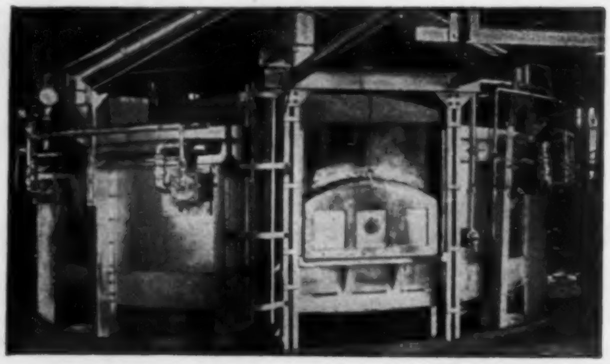

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Powder metal oil-retaining porous bronze bearings are described and illustrated in new booklet by Bound Brook Oil-less Bearing Co. Bulletin Fg-358.

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Metal Powders. Metals Disintegrating Co. Bulletin Ec-208a.

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Lead-base metals. Magnolia Me[illegible] Co. Bulletin Kf-422.

Cr-Ni-Mo Steels. A. Finkl & So[illegible] Co. Bulletin La-23.

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48-page catalog on manganese st[illegible] American Manganese Steel D[illegible] American Brake Shoe & Foundry [illegible] Bulletin Cg-9.

Oilite precision oil cushion-bro[illegible] bearings and other powder m[illegible] bar, plate and strip stocks are c[illegible] prehensively described in 140-p[illegible] catalog issued by Amplex [illegible] Chrysler Corp. Bulletin Dg-492.

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